NEXT MONTH

Oftentimes in the pages of *Chem. & Met.* we have called attention to the fact that petroleum refining is becoming more and more a chemical industry. We are now investigating the results of that trend in the light of increased opportunities for chemical engineers.

What kind of jobs do chemical engineers hold in this industry? What problems do they solve? What are their lines of advancement? How many are employed? What is likely to be the outlook for the future? . . . We hope to have the answers to all these questions and more next month in "Chemical Engineering Opportunities in Petroleum Refining."

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ESTABLISHED 1902

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C. M. ASHLEY, E. J. BARTA, F. R. BICHOWSKY, F. C. DEHLER, Z. G. DEUTSCH, H. J. GARBER, J. W. HUNTER, H. F. JOHNSTONE, C. L. MANTELL, D. F. OTHMER, J. C. PATTERSON, A. B. RAY, G. L. SIMPSON

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S. D. KIRKPATRICK, *Editor*
JAMES A. LEE, *Managing Editor*
THEODORE R. OLIVE, *Associate Editor*
M. A. WILLIAMSON, *Publisher*
HENRY M. BATTERS, *Market Editor*
MELVIN E. CLARK, *Assistant Editor*

EDITORIAL REPRESENTATIVES

PAUL D. V. MANNING, *68 Post St., San Francisco, Calif.*
E. S. STATELER, *520 N. Michigan Ave., Chicago, Ill.*
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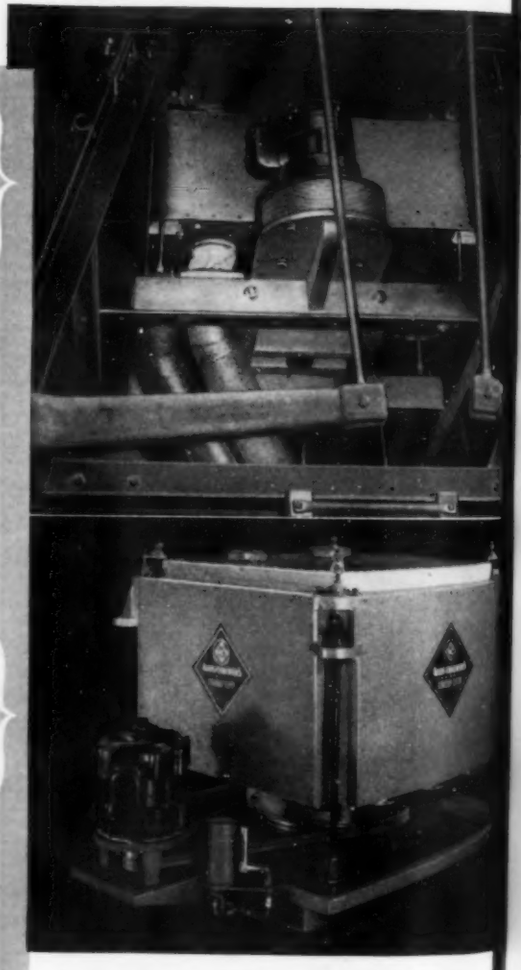

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CHEMICAL & METALLURGICAL ENGINEERING

ESTABLISHED 1902

MAY, 1940

S. D. KIRKPATRICK, *Editor*

FROM AN EDITORIAL VIEWPOINT

GREETINGS!

THIS MONTH we parade our new Spring clothes. From head to toe—from cover to index—we have been redesigned for appearance, legibility and simplicity. Our effort has been to conserve your reading time, to avoid the artificiality and excessive layouts which tend to distract the reader from the real facts within the articles. There are now more pictures on the front cover to give you more information about the contents of the issue. Even the paper and ink are new—better, more opaque. Nor are all the changes in form and format. On the pages that follow, we believe you will find plenty of evidence that *Chem. & Met.* editors are trying to live up to their pledge to give *Chem. & Met.* readers an increasing measure of service and satisfaction. How do you like it?

IT'S IN THE AIR

FOR SEVERAL YEARS we have felt that *Chem. & Met.* should publish a special section on air conditioning but for want of a novel and useful approach, we have not done so before. That novel approach has now been developed and its novelty checked with a considerable number of experts who have encouraged us to attempt a very difficult task. In a 48-page report in this issue, *Chem. & Met.* editors and contributors have extended the concept of air conditioning to cover practically any desired combination of gas and vapor. Thus our discussion becomes directly applicable to the wide range of industrial problems in drying and solvent recovery, heating and cooling, humidifying and dehumidifying.

Here the reader will find help on both theory and practice in what we believe to be a useful interpretation of fundamental knowledge and experience. If it stimulates chemical engineers to make a wider application of these basic principles throughout the whole range of the process industries, *Chem. & Met.* editors and contributors will have achieved their major purpose.

SCANDINAVIAN PULP

THE EXTENSION of the war to the Scandinavian countries has put a stop to the importation of pulp from Europe. While it is too early to be able to determine how long this situation may continue or to what extent the geographical and political changes brought on by the war will affect importations after peace returns to the world, the pulp and paper industry in America is already very much concerned. Paper manufacturers in this country have been depending upon Scandinavia for 20 per cent of their total consumption of chemical pulps. Since these pulps cannot be obtained elsewhere the shortage must be made up by domestic mills. To the chemical industry this increased production of pulp will mean a correspondingly large increase in demand for chemicals. To chemical engineers it presents an opportunity not only of making the domestic industry temporarily self sufficient but, through the application of technical skill and the development of higher operating efficiency, of translating this situation into a permanent asset.

OUR OWN CONSUMER MOVEMENT

MUCH OF THAT which is popularly known as the "consumer movement" is unsound, misguided and futile. Some of its leaders have proved to be communists, intent on destroying all of organized industry. Others, whose technical advice is often quoted on consumer purchasing, come pretty close to racketeering in the practice of their business. Yet however misguided and spurious the leadership, there is a growing demand on the part of household buyers for more information about the goods they purchase. As engineers we cannot con-

demn in theory the practice in the home of the same principles that have been developed and applied in industrial transactions. But we can help to make the practice more nearly conform with the theory.

Recently at the Chemists' Club in New York, a technical audience was told by a highly intelligent lady speaker that the difference between the housewife's transactions and those of her husband in industry was largely a matter of confidence and understanding. The smaller purchaser, she said, always regards the seller with suspicion while in the case of industrial purchases, there is a common ground of mutual understanding that dispels suspicion of sharp practice and unfair dealings. Just how safely one can generalize on such matters is questionable, but we can see in the lady's argument a beautiful case for branded merchandise. Isn't that, after all, one of the best means we have to build up recognizable values in confidence and good will—to dispel doubt and suspicion between buyer and seller?

Closer home to those of us in chemical engineering, however, is the growing demand on the part of the industrial buyer for more factual information about the products he buys. There is now more persistent questioning about specifications and performance and less tolerance for generalities and institutional claims. Most companies that advertise materials and equipment to engineering audiences are getting away from pretty girls and puppy dogs and substituting vital facts and figures. They realize that their advertisements are written for men who want to read about their jobs and their problems, not to get away from them. Publishers of reputable business papers and technical journals are urging their advertisers to "tell all"—that is to tell all that the reader wants to know about the product in order to determine its worth to him. With such a consumer movement on the part of the industrial buyers, we can find no fault.

FIND ROOM FOR MORE "LEARNERS"

Many Divisions of industry are a bit worried as to whether they may not be short of skilled operators for difficult posts if the pressure of war demands should reach their plants. Many process industries are so situated and need take account at this time of this possible difficulty.

Certain chemical engineering executives are solving this problem in a very skillful manner. They are taking on a larger number than usual of young college graduates. These young men are necessarily cubs who must be given considerable training before they are valuable as potential staff executives. Often they can be given such "cadet" experience as learners in overalls.

To fill such a post acceptably, a young man must be of good personality as well as suitably trained in the fundamentals of chemical engineering. He must be able to take an operating job under an old-time "practical" man without becoming too much of a nuisance. He must be willing to learn just as if he were a mere high school lad at his first job. Most important of all, he should realize that while he is getting this practical experience he is nothing more than an operating apprentice despite a handsome sheepskin at home.

And the chemical engineer who supervises these youngsters also has his responsibilities, as well as his troubles. He must make it clear to the youngsters that if they make good as operators they have something more than straw-boss jobs ahead. They must be given both the assurance, and the actual opportunity, of preparing themselves for responsible operating positions for which this routine with its drudgery will be a valuable experience. Not all of the boys will stick it out. But those who do, must be recognized both with salary increases and with tasks which will utilize some of their technical skill and stimulate their effort to grow in the job. The availability of such men for *both* operating *and* supervisory duties will be an acceptable reward to good management.

GREEN LIGHTS FOR BUSINESS

Washington Business Spokesmen are rubbing their eyes as they read the consent decree which defines certain price reporting activities that the National Container Association may now carry on. That trade group and the Department of Justice got together in a definition of prohibitive practices which also gives certain specific and permissive authorities of interest to industry in general.

Such a step will do a great deal to encourage both business executives and trade association leaders. It is evident that Uncle Sam as policeman wants to inform the citizenry what they may properly do as well as crack them over their knuckles when they reach out too far in their effort to get profits through "improper price influences." One wonders whether the new Attorney General can be persuaded to go as far as Secretary of Commerce Hoover once urged on a predecessor of the '20's. At that time it was Mr. Hoover's ambition to have the Department of Justice, after considered conference with business groups, give them a green light on proper constructive efforts.

No one should expect the Department of Justice or any other regulatory agency to make commitments that may not be revoked on the basis of new evidence of wrongdoing. Nor is it fair that proper appearing practices be allowed to continue if secondary effects contrary to public interest develop. The way to handle such cases is simple. The public officials who have granted temporary O.K. on procedures should be privileged to withdraw them. But only after notice of the withdrawal of privileges should those taking advantage of them be subject to either civil or criminal prosecution. It would seem as though a very straightforward business-like scheme of dealing could be set up within those limits. All will hope that this consent decree is a step in that direction.

CHEM. & MET. REPORT ON

Conditioning of Gases and Air

TO PLANT MANAGERS, SUPERINTENDENTS AND CHEMICAL ENGINEERS

To an ever increasing extent chemical engineers are having to deal with the psychrometric properties of mixtures of gases and vapors, and particularly with the means of separating them. Psychrometric properties of air have been studied for years and their understanding has led to the science of air conditioning. The broader view of this question, where any gas and vapor mixture may be considered, is not so well understood. The purpose of this report therefore is to show the fundamental principles that apply not only to air and water vapor, but to any gas-vapor mixture that may be met in processing, drying or solvent recovery. To this end, the report covers methods of making and using charts of psychrometric properties; comparisons among different types of chart; means of producing gas-vapor mixtures, or of separating them by cooling, absorption and adsorption; equipment used in the processing of gas-vapor mixtures; and finally a section devoted to showing how the principles, methods and equipment described fit into specific problems in air conditioning, air drying and the recovery of volatile solvents other than water.

CHEMICAL AND METALLURGICAL ENGINEERING

Report Series A, No. 3

TITLE OF REPORT Conditioning of Gases and Air

TO Chemical Engineers

FROM Chem & Met Editors and Contributors

DATE May 1940

INTRODUCTION

Air conditioning, a term which is now so familiar that it has even been applied descriptively, if incorrectly, to straw hats and porous underwear, is actually new as engineering sciences go, for the developments which led to its general use took place hardly more than a quarter century ago.

Chemical engineers like to recall that it was one of their number, Grosvenor, who in 1908 laid the foundations for air conditioning with the presentation of his paper on "Calculations for Dryer Design," to the infant American Institute of Chemical Engineers, founded in that year. Grosvenor departed from meteorological practice in choosing the pound of dry air, rather than the cubic foot of air as his base, and so made possible a notable simplification in calculations. However, it remained for Carrier, a mechanical engineer, to foresee the full range of practical possibilities in manipulating the composition and temperature of air. In 1911 Carrier published his famous Rational Psychrometric Formulae, and by 1915 he had established his own engineering firm to put his formulae to practical use.

But air conditioning is only one phase of what can be done with gas and vapor mixtures when an understanding is gained of the effects of temperature and pressure changes upon the mixture, or of bringing the mixture into contact with adsorptive agents. Air conditioning is thus a special case of the broader subject of Conditioning of Gases and Air which is the theme of this *Chem. & Met.* Report.

It is with the idea therefore of showing this generality, and of pointing to the specific means employed in psychrometric processes, that this report has been planned and prepared. If it falls short of the aim, it is not through any lack of interest or cooperation on the part of the numerous authorities whose signed contributions appear on the following pages. Particularly we wish to record our appreciation for the assistance given by the authors of the leading article, Drs. E. J. Barta and H. J. Garber of the University of Cincinnati chemical engineering department, whose suggestions originally led to this Report.—Editors.

Principles—

IN THIS special report *Chem. & Met.* has set itself to the task of bringing a measure of clarity to a subject which, although not especially complex, tends to be decidedly confusing to engineers who do not have occasion to work with it constantly. Processes dealing with the properties of mixtures of gases with condensable vapors are encountered in numerous guises and these processes take on industrial importance in almost endless variety. Atmospheric air, with the water vapor it contains, is a universal experience, affecting human physiology and the properties of materials alike. Because of its universality, the study of air properties has been carried much beyond that of other possible atmospheres, but there is no fundamental difference between the behavior of an air-water vapor mixture and a mixture of, say, nitrogen and acetone vapor.

What we are concerned with in such mixtures is a combination of a gas such as air or nitrogen, which is far from its condensation point, with another gas such as water or acetone vapor, which is by comparison near its condensation point. We have then to deal with a mixture which may change in the proportions of its constituents owing to condensation or vaporization and our problem is to determine how such changes take place, how they can be brought about and controlled.

The report that follows, therefore, attempts to give brief answers to the principal questions in industrial psychrometry, discussing them in four groups of articles. Fundamental principles of gas-vapor mixtures are taken up by Drs. E. J. Barta and H. J. Garber who present four psychrometric charts for solvent vapors. In this same section a staff article contrasts the principal variations in psychrometric chart forms, showing also their similarities and simplifying this confusing matter. Dr. D. F. Othmer, in a third article, presents a totally new type of psychrometric chart.

And Practice

A SECOND SECTION of the report assembles a group of articles discussing the industrially important methods of separating gas-vapor mixtures, including condensation by refrigeration; by salt solutions such as lithium and calcium chlorides, and other liquids such as the glycols; by adsorption with such solids as activated carbon, silica gel and activated alumina. A comprehensive attack by Mr. J. C. Patterson on the problem of choosing among the various dehumidification methods for particular applications concludes the section.

A third section comprises four articles dealing with the principal types of equipment encountered in psychrometric processes and includes papers on compression, heat exchange, gas cleaning and gas-liquid contacting.

Then, to tie together the entire report, a fourth section contains a group of articles on applications, the aim of which is to show how the principles, practice and equipment of the earlier articles fit together into practical operating processes for air conditioning, solvent recovery and drying.

Use of Psychrometric Principles

By *EDWARD J. BARTA* and *HAROLD J. GARBER*, department of chemical engineering, University of Cincinnati, Cincinnati, Ohio. **This comprehensive paper explains the applications of psychrometric data in chemical engineering processes, how such data for any gas-vapor mixture can be calculated and plotted, how data can be secured, and how they are used in the solution of a typical chemical engineering problem.**

DURING the past 30 years numerous contributions have been made to the theory of psychrometric processes, with particular advantage in the field of air conditioning. Probably because of the universal availability of air and water, most of the experimental and theoretical work has been on the psychrometry of these substances, although it has been recognized for some time that similar principles apply generally to all mixtures of gases with condensable vapors. Prior to 1908 neither sufficient data nor an adequate and simple mathematical plan for stating the properties of gas-vapor systems were available. In that year, however, Grosvenor[1] first established a rational mathematical basis for expressing psychrometric principles in chart form. Since that time numerous other excellent contributions to the science of psychrometry have been made.[2]

At present the most frequent applications of psychrometry are in air conditioning and drying, although rapid progress is also being made in the recovery of solvents. Comfort air conditioning attempts to improve the properties of air by adjusting the final temperature and moisture content for the maximum comfort of individuals; and industrial air conditioning, to obtain optimum atmospheric conditions for materials in process. For example, paper or fabric impregnated with urea-formaldehyde resins becomes brittle and difficult to handle after drying unless stored and conditioned in an atmosphere of high humidity. In lithography the register of the several colors may be affected by atmospheric changes, a difficulty which is cured by air conditioning. Leather drying at high humidity and relatively low temperature is necessary to avoid undesirable effects. Similar requirements are met in kiln drying of lumber where high humidity in the initial stages is needed to prevent shrinkage, cracking and warping.

Many industrial processes involve the vaporization of a liquid, such as water or a solvent, into an atmosphere of air or other gas. When the process is used to remove the liquid from a solid or semi-solid, it is commonly referred to as drying and, in the case of removal of water, is met in the making of such representative products as textiles, paper, leather, wood, soap, salt, soda ash and sugar. Such processes require ability to compute the vapor-carrying power of the air as well as the effect of drying the stock, or storing the dried stock, in a controlled atmosphere.

Removal of organic solvents has not received the same attention that has been given to air-water vapor mixtures. It should be emphasized that any gas of relatively low boiling point, other than air, may be used as the atmosphere, which may be desirable in dealing with explosive or flammable materials. Flue gas, nitrogen, carbon dioxide or steam, for example, may be used to avoid hazard. When the process employs air-vapor mixtures, however, concentrations are ordinarily maintained below the lower explosive limit, which greatly increases the problem of solvent recovery.

A few industries in which organic solvent removal is practiced and where a knowledge of the psychrometric relationships involved is important may be mentioned. The dry cleaning industry, one of the larger users of organic solvents, employs petroleum fractions (Stoddards Solvent) to a large extent, and more recently substances such as carbon tetrachloride, trichlorethylene, and perchlorethylene. Solvent removal by centrifuging and drying with heated air removes the solvent, and calls for solvent recovery from the air for most economical operation. In manufacture of synthetic resin products and numerous organic solid chemicals ethanol is a common agent and again air drying is often used. Acetone, one of the solvents used in smokeless powder manufacture, is vaporized by air drying, and the venting of the drying air to the atmosphere results in a loss of valuable solvent which for most economical operation should be recovered by a solvent recovery process. All of these recoveries and many others are capable of treatment by psychrometric principles, as are vola-

CHEM. & MET. REPORT ON

Conditioning of Gases and Air

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cilization of benzene in rubber manufacture and of gasoline in carburetion. Recovery of mixed solvents as obtained in lacquer drying operations may also be based on psychrometric principles, although the characteristics of mixed vapors are not yet fully investigated.

The recovery of vapors from vapor-gas mixtures may be accomplished in a number of ways. Such recovery, which is here referred to as dehumidification (the term having the broader meaning of separation of any vapor from any gas), may be carried out by absorption, adsorption, chemical reaction, cooling, and compressing. Each of these methods has its advantages and disadvantages, although no attempt at evaluation of the relative merits will be made here.

Absorption involves the removal of the volatile constituent from the atmosphere by an absorbing medium which is brought into contact with the gas-vapor mixture, usually in countercurrent relation. Completeness of absorption is a function of the contact time, degree of dispersion, and concentration of the volatile constituent in the gas and liquid phases.[3] Where the volatile constituent is valuable, its recovery from the absorbent may be accomplished by steam distillation, stripping or rectification. Benzene from coke oven gas, propane and butane from petroleum refinery gases, and ethanol or acetone from drying air are examples of organic vapor removal.

Activated Solid Adsorption

Adsorption with activated solids plays an important part in the recovery of organic vapors, as well as the separation of water vapor from air. In part the ordinary gas mask functions through the adsorptive action of activated carbon, which material is now also used to a considerable extent in the recovery of organic vapors from industrial atmospheres.[4] The other industrially important adsorbents, silica gel and activated alumina, are capable of adsorbing organic vapors, but have a specific preference for water vapor and so are used chiefly for the drying of air and gases of their contained water vapor. With these adsorbents, regeneration is accomplished by heating, either directly or with a suitable stripping medium such as steam or hot gases or air.

Chemical removal of vapors is practiced only in the case of water vapor, which may be separated from the gas stream which such reagents as lime, calcium chloride, phosphorus pentoxide, magnesium perchlorate, and anhydrous copper sulphate. An interesting application is the production of absolute ethanol by passage of the azeotropic vapors over anhydrous calcium sulphate.

Condensation of volatile fractions in gaseous systems by cooling for the removal of sensible and latent heat is a much used method, and relatively simple. However, to avoid excessive cooling requirements, the system must be one with a large amount of vapor, the partial pressure of which is near the saturation value of the system. Proper design in the case of a dryer will usually assure adequate concentration, but a recirculation of the drying atmosphere is ordinarily necessary to avoid vapor loss with a reasonable amount of cooling. Numerous examples of this method are available, most important of which is ordinary air conditioning. Drying of blast furnace air, and of carbon dioxide for dry ice manufacture, as well as the recovery of solvents in resin manufacture, in making organic chemicals, in soy bean oil production, and in oil recovery from meat scraps and seeds, are other examples.

Compression, which itself accomplishes some condensation of the vapor, is sometimes employed before refrigeration of the vapor-gas mixture, since the vapor-carrying capacity of a gas decreases as the total pressure of the system increases. Application of this method is found in butane and propane recovery, and in the drying of nitrogen-hydrogen mixtures for ammonia synthesis.

Gas-vapor processes generally require close attention to means for propelling the mixture and for conducting it from place to place. Ejectors, fans, blowers and compressors are employed[4, 5] (see also pp. 317–18 this issue.—Ed.) for the first purpose, and ducts and conduits[6], for the latter. Since heat transfer is an important characteristic of both humidification and dehumidification operations of all kinds, considerations of change in latent and sensible heat enter into the calculations and heat transfer equipment for heating and cooling becomes vital. Means for economical production of the required heating or cooling effect must be supplied, as well as suitable refrigerants and fuels, and media for transferring the heating or cooling effect to the place of use.

Operations in which the flow of all materials is continuous are desirable in processes involving mixtures of gases and vapors. Although it is a common impression that continuous operation is feasible only in large scale production, many small scale continuous operations have been made to function satisfactorily in recent years.

Control of operating conditions in psychrometric processes is mandatory for optimum results, since such processes depend on the desired relations of temperature, pressure, gas flow and humidity. Temperature, for instance, determines the rate of vaporization and the concentration of the volatile constituent in the atmosphere. The pressure of vaporizing operations may be either above or below atmospheric pressure. Since the total pressure of the system and the partial pressure of the volatile material determine the concentration of the latter, the influence of the total pressure (which will be discussed later) is of importance. The effect of gas flow, of course, is to bring the proper amount of atmosphere per unit of time into contact with the stock so as to accomplish a definite amount of evaporation. And the rate at which this evaporation can take place is determined by the fourth major variable, humidity. Humidity determines the vapor pressure gradient and controls the final equilibrium liquid content in the solid.

Psychrometric Relationships

In solving humidification and dehumidification problems it is customary and convenient to display the basic relationships used to produce the numerical solution in graphical form on psychrometric charts. The items placed on these charts are the specific mass and thermal properties of the mixtures dealt with, since these are the properties which are most useful for solving problems. In particular, the items most frequently graphed on psychrometric charts are:

1. Dry volume: the volume occupied by unit mass of dry carrier gas, V_d.
2. Saturated volume: the volume occupied by unit mass of the carrier gas and the vapor which saturates it, V_s.
3. Humid heat: the heat necessary effect a 1-deg. elevation of the temperature of unit mass of the carrier gas and the vapor it carries, s.
4. Heat of vaporization of the vapor which forms the liquid: the heat necessary to transform unit mass of vapor-former from the liquid to the vapor state, r.
5. Total heat of saturation vapor above arbitrary reference temperature: the heat necessary to transform the saturation vapor for unit mass of carrier gas from the state at which it exists at the reference temperature (usually 0 deg. F.), to its state in the saturated mixture, h_s.
6. Total heat of saturated carrier above arbitrary reference temperature: the heat required to raise the temperature of unit mass of carrier gas and the vapor which saturates it from the reference temperature to the saturation temperature, h_t.
7. Saturated humidity: the mass of vapor carried by unit mass of carrier gas at saturation, H_s.
8. Percentage absolute humidity: the ratio of actual humidity to saturated humidity, $100H/H_s$.
9. Vapor pressure of the vapor-former: the pressure of vapor above the liquefied vapor-former at equilibrium, p_s.
10. Adiabatic humidification paths: the locus of humidity-temperature shift of the gas mixture as it cools during isenthalpic (constant total heat) interchange of sensible heat of the gas mixture for heat of vaporization and superheat of the vapor-former. With the exception of the humid heat, all of the items are plotted as functions of the temperature; the humid heat is plotted against humidity.

If it is assumed that both the carrier gas alone and the carrier-vapor mixture behave as perfect gases, the dry and saturated volumes are:

$$V_d = \frac{359}{M}\,\frac{P}{760}\,\frac{(t+460)}{492}$$

$$= 0.00096\,P\,(t+460)/M \qquad (1)$$

$$V_s = 359\,\frac{P}{760}\,\frac{(t+460)}{492}\left(\frac{1}{M}+\frac{H_s}{m}\right)$$

$$= 0.00096\,P\,(t+460)\left(\frac{1}{M}+\frac{H_s}{m}\right) \qquad (2)$$

Since specific heats of gas and vapor

Table of Symbols

A Constant, deg. Rankine (deg. F. abs..)
B Constant, dimensionless.
C Specific heat at constant pressure of carrier gas, B.t.u. per lb. and deg. F.
c_l Specific heat of liquid vapor-former, B.t.u. per lb. and deg. F.
c_s Specific heat of solid vapor-former, B.t.u. per lb. and deg. F.
c_p, Specific heat at constant pressure of gaseous vapor-former, B.t.u. per lb. and deg. F.
D_i Specific energy of distortion vibration, B.t.u. per linkage.
e Sensible heat for cooling or heating air-vapor mixture, B.t.u.
f Heat of fusion of vapor-former, B.t.u. per lb. and deg. F.
G Total weight air-vapor mixture, lb.
g Weight dry air, lb.
H Humidity, lb. vapor-former per lb. carrier.
H_s Saturated humidity, lb. vapor-former per lb. carrier.
h_s Total heat of saturation vapor above reference temperature, B.t.u. per lb. carrier.
h_t Total heat of saturated carrier above reference temperature, B.t.u. per lb. carrier.
j Total heat removed from saturated air vapor mixture, B.t.u.
k Constant, dimensionless.
M Molecular weight of carrier, lb. per lb. mol.
m Molecular weight of vapor-former, lb. per lb. mol.
n Number of atoms per molecule, dimensionless.
P Total pressure of gas-vapor mixture, mm. mercury.
p Partial pressure of vapor, mm. mercury.
p_s Vapor pressure of vapor-former, mm. mercury.
q Number of linkages between atoms per molecule, dimensionless.
q_i Number of linkages of the ith kind per molecule, dimensionless.
R Percentage relative humidity, dimensionless.
r Latent heat of evaporation of vapor-former, B.t.u. per lb.
s Humid heat of carrier-vapor mixture, B.t.u. per lb. carrier per deg. F.
T Temperature, deg. Rankine (deg. F. abs.).
t Dry bulb temperature, deg. F.
t_f Temperature of fusion of vapor-former, deg. F.
t_r Reference temperature, deg. F.
t_s Adiabatic saturation temperature, deg. F.
t_w Wet bulb temperature, deg. F.
V Humid volume of gas-vapor mixture, cu.ft. per lb. carrier.
V_d Dry volume of carrier, cu. ft. per lb. carrier.
V_s Saturated volume of gas-vapor mixture, cu. ft. per lb. carrier.
V_i Specific energy of valence distortion, B.t.u. per linkage.
v_s Molal volume of the vapor-former as a gas, cu. ft. per lb. mol.
v_l Molal volume of the vapor-former as a liquid, cu. ft. per lb. mol.
W Vapor produced, lb.
w Vapor in recirculated air, lb.

Subscripts: c, cooling; h, heating; i, specific linkage; r, reference; 1, conditions at air entrance; 2, conditions at air exit.

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mixtures are additive with respect to the components

$$s = C + c_p H \qquad (3)$$

Experimental or suitably calculated values of the latent heat of vaporization of the vapor-former are used.

Depending on the physical state of the vapor-former at the reference temperature, the expressions for the total heat take on slightly different forms. If the vapor-former is a solid at the reference temperature the total heat of the saturation vapor above the reference temperature is the sum of the transition and sensible heats and is given by:

$$h_s = H_s [c_s (t_f - t_r) + f + c_l (t_s - t_f) + r_s] \qquad (4)$$

The heat required to elevate the temperature of unit mass of carrier from the reference temperature to the saturation temperature is $C(t_s - t_r)$, hence the total heat of the saturated carrier above the reference temperature is

$$h_t = C(t_s - t_r) + h_s \qquad (5)$$

If the vapor-former exists as a liquid at the reference temperature the first two terms of Equation (4) are dropped and t_r is substituted for t_f.

Based upon Avogadro's hypothesis and Dalton's law of partial pressures, the molal ratio of the vapor to carrier in a humid mixture is the same as the ratio of the respective partial pressures of these two components in the mixture. At saturation the partial pressure of the vapor-former in the mixture is its vapor pressure at the temperature in question and the partial pressure of the carrier is the difference between the total pressure of the system and the vapor pressure of the vapor-former. Upon introducing the molecular weights of the two components the molal ratio is transformed into the corresponding weight ratio. Setting the mass of the carrier gas at unity the definition of saturated humidity results:

$$H_s = \frac{p_s}{(P - p_s)} \frac{m}{M} \qquad (6)$$

The humidity of the system under unsaturated conditions in terms of the partial pressure of the vapor former and the other variables is

$$H = \frac{p}{(P - p)} \frac{m}{M} \qquad (7)$$

The percentage absolute humidity is the ratio of Equation (7) to (6) or

$$100 \frac{H}{H_s} = 100 \frac{p(P - p_s)}{p_s(P - p)} \qquad (8)$$

Meteorologists and engineers frequently make use of the quantity known as percentage relative humidity which is defined as the ratio of the actual partial pressure of the vapor-former in the mixture to the saturation vapor pressure of the vapor-former at the temperature chosen

$$R = 100 (p/p_s) \qquad (9)$$

It is apparent upon inspecting Equations (8) and (9) that percentage relative humidity and percentage absolute humidity are not the same quantities. If Equation (9) is inserted into Equation (8), an expression results which may be used as the basis for the construction of nomographs interrelating relative humidity, humidity, and temperature

$$R = 100 (H/H_s) (P - p)/(P - p_s) \qquad (10)$$

Although most of the humidity charts which have appeared in the literature do not have the vapor pressure of the vapor-former plotted, it is a good plan to incorporate this on the chart where it will be quite handy for occasional calculations in which it is required, particularly when the system under consideration is at a different pressure than that for which the chart is constructed.

When dry or unsaturated carrier gas is passed over stock wet with vapor former and the system is insulated against heat losses and gains, a simultaneous adiabatic material and heat transfer occurs between the liquid and gas. A portion of the liquid vaporizes and superheats to the gas temperature, the heat to accomplish this process being abstracted from the gas mixture. The result of this process is that the gas becomes more humid and colder, approaching saturation as the process of adiabatic humidification continues. The path taken by the gas mixture during such processes is of paramount importance in humidification and dehumidification work.

Experience has shown that as adiabatic humidification occurs, the thermal state of the liquid shifts until it attains a fixed temperature designated as the wet bulb temperature. The adiabatic humidification curves drawn on humidity charts are constructed under the assumption that the liquid vapor-former is always at the adiabatic saturation temperature, i.e., the intersection of the adiabatic humidification curve and the 100 per cent saturation curve, and that all evaporation occurs at this temperature; actually the wet bulb temperature may not be the same as the adiabatic saturation temperature.

The locus of the family of adiabatic humidification curves can be obtained by writing the criterion for all isenthalpic processes, i.e., the summation of the heat transferred is zero. Assuming that the process is differential in nature, i.e., that the gas increases dH in humidity and decreases dt in temperature, this expression results:

$$[r_s + c_{p_s}(t - t_s)]\, dH + [C + H c_{p_s}]\, dt = 0 \qquad (11)$$

Upon rearranging variables

$$\frac{dH}{C + H c_{p_s}} = -\frac{dt}{r_s + c_{p_s}(t - t_s)} \qquad (12)$$

Actually all of the specific heat terms in the above equations are functions of temperature, hence integration of (12) cannot be accomplished in a direct manner. Fortunately, in the ranges ordinarily encountered in in-

dustrial work, the specific heats of both carrier and vapor former, C and c_{p_s}, change very little, so that it is possible to insert mean values in Equation (12) for these terms with slight loss in accuracy. Under these conditions, the variables are completely separated and the integration may be accomplished directly. Carrying out the integration between the variable initial conditions (H, t) and the adiabatic saturation values (H_s, t_s) and rearranging terms results in the working equations for adiabatic humidification

$$H = H_s - (H_s + C/c_{p_s})(1 + F) \qquad (13)$$

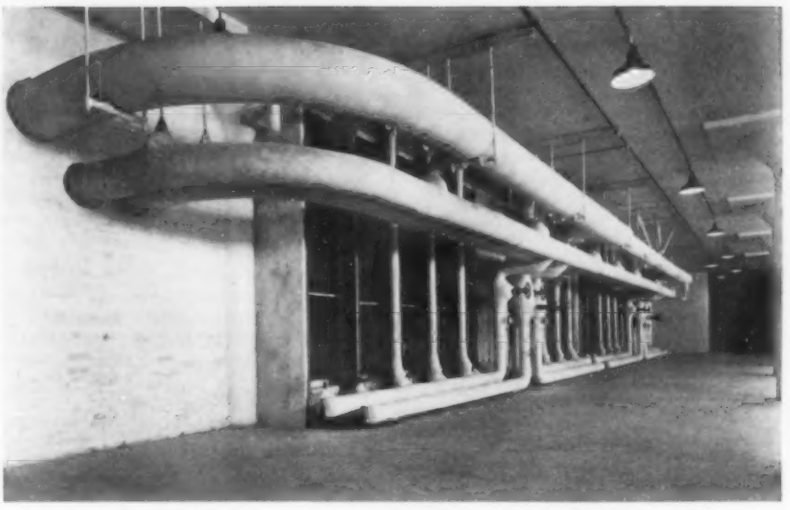
where $F = r_s/[c_{p_s}(t - t_s)]$ (13a)

Equations (13) and (13a) were used to construct the adiabatic humidification curves in the charts appearing in the insert facing page 292.

All of the expressions (1) through (13a) are perfectly general in nature and may be applied to any carrier gas and vapor-former at any total system pressure, provided the assumptions made in their derivation are not transgressed. Few charts for mixtures other than air and water at one atmosphere pressure have appeared in the literature. The four charts in the insert mentioned above are representative psychrometric diagrams for more common industrial solvents.

The temperature attained by the wet bulb thermometer in air-water vapor mixtures almost coincides with the adiabatic saturation temperature of the gas mixture. This is the result of the fact that the quotient of the heat transmission coefficient through water vapor films and the product of the humid heat of the mixture adjacent to the films and the mass transfer coefficient through the film is very nearly unity.[7] Thus, the wet and dry bulb temperature readings for air water-vapor mixtures give a very convenient means for determining the humidity of the air by passing down the adiabatic humidification curve originating at the wet bulb value at saturation and reading off the humidity which corresponds to the dry bulb temperature. This unusual good fortune in the case of air-water vapor tends to give the erroneous impression that the wet and dry bulb temperature readings for *any* system of carrier and vapor are sufficient to determine the humidity of mixtures by the use of the adiabatic humidification curves.

The wet bulb temperature of a mixture approaches the adiabatic saturation temperature the more humid the mixture becomes with respect to the vapor-former. At saturation the wet bulb temperature and adiabatic saturation temperature are the same. Thus, in order to use the wet and dry bulb temperatures to determine the humidity of a mixture the wet bulb thermometer should be placed in a small insulated saturating device in the system so that the reading observed is that in air which has been adiabatically saturated. Since, at saturation, the wet and dry bulb readings are alike, the accuracy of the humidity determination will be greater when the wet and dry bulb thermometers placed in the small saturating device read almost alike. For precision work, either the dewpoint should be determined or the concentration of the vapor in the mixture should be obtained by suitable chemical means.



Intake chamber of spinning room air conditioner in Industrial Rayon Corp.'s new Painesville plant, which conditions 500,000 c.f.m. of fresh air

Constructing Humidity Charts

In order to construct humidity charts the following physical quantities must be available:

1. Vapor pressure data for the vapor-former over the temperature range to be covered.
2. Molecular weights of the carrier and vapor in the gaseous state.
3. Specific heats of the vapor-former in the solid (if necessary), liquid, and vapor state.
4. Specific heat of the carrier gas.
5. Latent heat of evaporation and fusion (if necessary) of the vapor-former.

Frequently only a portion of the required data can be found in the literature; in particular, information on vapor pressures, heats of vaporization, and specific heats of vapors are scanty. In such cases, certain trustworthy interpolation and calculation rules are quite welcome. A few of the methods which have been found serviceable in supplying missing data or augmenting scanty information are reviewed in the following paragraphs.

When the vapor pressure of a substance is known only at a few temperatures, several courses of attack are open to approximate the vapor pressure curve:

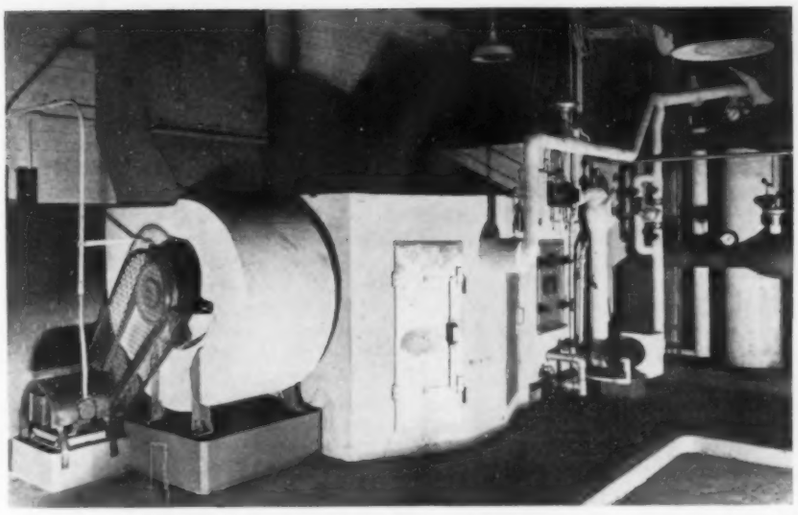
1. Construct the best straight line through a plot of the common logarithm of the known vapor pressures versus the reciprocal of the corresponding known absolute temperatures (or see Othmer's method, page 296.—Ed.) This procedure is based upon the fact that the vapor pressure of many substances can be expressed in the form

$$\log p_s = A/T + B \qquad (14)$$

with sufficient precision for industrial work. Equation (14) has a theoretical basis in that it is derivable from the exact Clapeyron-Clausius equation and several assumptions, the most strenuous of which are that the vapor behaves as a perfect gas and that the heat of vaporization is constant over the temperature range for which the equation is applied.

2. Construct a Dühring line plot of the temperatures of the vapor-former and a standard substance for those temperatures at which the vapor pressures of the vapor former and standard substance are alike. Also construct the vapor pressure curve of the standard substance on this same plot. Since the Dühring line plots corresponding temperatures for equal vapor pressures, from this plot and the vapor pressure curve for the standard substance, it is possible to derive the vapor pressure curve of the substance for which the data are limited. The accuracy will be high if the standard substance is very closely related chemically to the liquid in question.[8]

3. Construct a Cox chart[9] for the liquid, using a standard substance which is closely related chemically to the liquid in question. This is accomplished by drawing a system of parallel vertical lines in logarithmic sequence covering the vapor pressure range desired and forcing the vapor pressure of the standard substance to be a straight line by drawing it in as a straight line on the plot. This arbitrary procedure results in a satisfactory temperature modulus and range when the line is constructed slightly to the left of the center of the sheet, with a slope of approximately unity. Having adopted this line as the vapor pressure curve for the standard substance, the resulting temperature scale which is to be



A smaller one of 13 complete air conditioning units in Industrial Rayon's Painesville plant: conditioning this plant takes up to 1,500 tons of refrigeration

used in the chart is determined from the vapor pressure-temperature data for the standard substance. Upon plotting the few available points for the liquid in question on the chart and drawing in the best straight line through these points, the vapor pressure curve for the liquid is derived.

Calingaert and Davis[10] have discovered that when a Cox chart is constructed for homologous or otherwise very closely related compounds, the vapor pressure curves converge to a common point. Thus, if the liquid in question is closely related to a group for which the common point of intersection of the vapor pressure curves is known, it is necessary to have only one vapor pressure at one temperature to determine the vapor pressure curve for the system. In such cases, since the boiling point of almost all liquids is on hand or can be obtained, the boiling temperature suffices for the determination of the vapor pressure curve.

At the present writing no general expression nor method has been presented for calculating the precise heats of vaporization of any liquid at any chosen temperature. The more serviceable methods which are available to estimate latent heats are based on the Clapeyron-Clausius equation

$$\frac{dp_s}{dT} = \left(\frac{mr}{T(v_s - v_l)}\right) \qquad (15)$$

The heat of evaporation of any substance can be calculated with precision by the use of Equation (15) if data on vapor pressures, molecular dissociation, and molal volumes of the liquid and vapor are known for temperatures over the range desired. A modified Clapeyron-Clausius equation results when it is assumed that the molal volume of the liquid is negligible in comparison to the molal vapor volume, that the vapor obeys the ideal gas law, and that molecular weight of the vapor does not change:

$$r = 1.99\frac{T^2}{mp_s}\frac{dp_s}{dT} \qquad (16)$$

The above equation permits calculation of the heat of evaporation if the vapor pressure data are had. However, since it is inconvenient to obtain the value of the derivative (the slope of the vapor pressure-temperature curve) at the desired temperatures, it is possible to avoid this step by writing a companion equation identical to (16) for some reference substance for which accurate vapor pressure data and heats of evaporation are known. This reference substance should be similar chemically to the substance for which the data are sought. Combination of the modified Clapeyron-Clausius equations for the reference and working substance results in

$$r = r_r\frac{T^2}{T_r^2}\frac{p_{sr}m_r}{p_s m}\frac{dp_s}{dT}\frac{dT_r}{dp_{sr}} \qquad (17)$$

If a Dühring plot is made for the temperatures of the two liquids for equal vapor pressures, the slope of the line obtained is equal to the product of the two derivatives in (17), or

$$\frac{dp_s}{dT}\frac{dT_r}{dp_{sr}} = k \qquad (18)$$

Combining Equations (17) and (18), a serviceable expression is obtained for comparing the heats of evaporation of the two liquids at temperatures at which the vapor pressures are equal

$$r = kr_r\frac{m_r}{m}\frac{T^2}{T_r^2} \qquad (19)$$

At relatively low pressures, when the vapor behaves approximately as an ideal gas, Equation (19) gives results which are sufficiently accurate for use in constructing psychrometric charts.

Recently an excellent method has been developed to calculate the specific heats of organic vapors at various temperatures.[11] The method, which has a sound theoretical basis, sums up the energies of translation, rotation, valence vibration, and deformation vibration of the molecule, as additive functions of the specific groupings in the molecule over a wide temperature range. The expression which applies is

$$c_{p_s} = \frac{1}{m}\left(7.96 + \Sigma q_i V_i + \frac{(3n-6-\Sigma q)}{q} \times \Sigma q_i D_i\right) \qquad (20)$$

where the summation indicated is to be applied to the different types of linkages in the vapor molecule. In the above expression n is the total number of atoms per molecule, q is the number of linkages between the atoms in the molecule, V_i is the specific valence vibration energy, D_i is the specific deformation vibration energy, and q_i is the number of linkages of each specific type present. Fig. 1 gives the variation of V_i and D_i of some of the commoner linkages which have been determined as a function of temperature. The agreement of calculated values of specific heats of organic vapors from Equation (20) with experimentally determined values is usually within 3 per cent over wide temperature ranges.

If psychrometric data are presented in terms of percentage relative humidity and temperature, it is convenient to convert these to the equivalent humidities when solving numerical problems. The conversion may be made by the use of Equation (10) expressed either in analytical or graphical form. Fig. 2 is such a chart for air-water systems at 1 atm. total pressure. When the total system pressure P is fixed, H_s and p_s become single valued functions of the temperature as determined by the vapor pressure curve for the vapor-former and Equation (6), and p becomes a single valued function of H as specified by Equation (7). Under these conditions Equation (10) is made up of three separable functions of the variables H, t, and R; it may be charted for any total pressure for any system in the same form as is exhibited in Fig. 2.

Psychrometric Problem Example

Canvas is continuously impregnated with an ethanol-resin solution, 500 lb. of the solution containing 40 per cent ethanol by weight being consumed per hour. After impregnation, the canvas enters an insulated dryer at a temperature of 70 deg. F., passing through the unit countercurrent to recirculated air. The air enters the dryer at 135 deg. with a humidity of 0.01 with respect to ethanol. The air vapor mixture leaves the dryer at a temperature of 70 deg. F. and flows to the cooling condensation system. The canvas leaving the dryer has a negligible ethanol content and is at the adiabatic saturation temperature of the air. No heat is added to or lost from the dryer. It is required to calculate: (*a*) Absolute humidity of the exhaust air with respect to ethanol; (*b*) weight and volume of air blown into the dryer;

(*c*) weight and volume of air blown out of the dryer; (*d*) temperature to which air is cooled in the ethanol recovery system; (*e*) heat removed in recovery of the ethanol; (*f*) heat added to the air before return to the dryer; (*g*) quantity of ethanol recovered from the condenser.

Solution to (*a*)—Since the humidification process is adiabatic, the humidity-temperature shift originates at the point (t_1, H_1) located at (135, 0.01) on the ethanol-air chart facing page 292, and passes along an adiabatic humidification curve drawn parallel to the nearest curve on the chart through the point (135, 0.01). The movement stops when the temperature is decreased to 70 deg. F. as specified by the problem; the humidity is 0.051 as given by the location of the point (t_2, H_2) = (70, 0.051) located on the adiabatic humidification curve, and corresponds to 49 per cent of the saturated humidity for 70 deg. F. air.

Solution to (*b*)—If it is assumed that 100 per cent of the air is recirculated through the system, then all of the ethanol evaporated must be carried out by this air. Letting g = pounds of dry air circulating per hour and W = the total evaporation per hour then $g = W/(H_2 - H_1) = 300/(0.051-0.010) = 7{,}317$ lb. dry air per hour, and $G = g + w = 7{,}317 + (7{,}317)(.01) = 7{,}390$ lb. total weight per hour. The volume occupied by the above air may be calculated directly from the psychrometric chart or from the working equation. From the chart, the hot air passed into the dryers has a percentage humidity, dry volume and saturated volume of 0.80, 15.0, and 25.9 respectively. Hence, the volume of the gas at this point per pound of dry air is: $V_1 = V_d + H(V_s - V_d)/H_s = 15.0 + 0.008\ (25.9-15.0) = 15.1$ cu. ft. per pound dry air. The working equation gives the same result. $V_1 = 0.73\ (t + 460)\ (0.0345 + 0.0217H) = 0.73\ (135 + 460)\ [0.0345 + (0.0217)\ (0.010)] = 15.1$ cu. ft. per pound dry air. Therefore, total volume entering the dryer per hour = (7,317) (15.1) = 110,500 cu. ft. per hour.

Solution to (*c*)—By an identical procedure the total weight of air leaving becomes $g + w + W = 7{,}317 + 73 + 300 = 7{,}690$ lb. The volume of exit air from the dryer is equal to: $V_2 = V_{da} + H_2\ (V_s - V_d)_2/H_{s2} = 13.35 + 0.49\ (14.22 - 13.35) = 13.78$ cu.ft./lb. Total volume leaving is (7.317) (13.78) = 100,800 cu. ft./hr.

Solution to (*d*)—The ethanol-air mixture must be cooled and sufficient ethanol must condense so that the residual air-vapor mixture has a humidity of 0.010. It is assumed that the air-vapor mixture is cooled at constant humidity to the temperature of saturation and subsequently along the saturation humidity curve to such a temperature that the desired amount of condensation is obtained.

Reading from the ethanol-air chart directly, the temperatures corresponding to saturated humidities of 0.051 and 0.010 are 50.0 deg. and 10.0 deg. F. respectively. The air-vapor must therefore be cooled to 10.0 deg. F.

Solution to (*e*)—To accomplish the above condensation heat must be removed from the system. Sensible heat must be removed while cooling from 70 to 50 deg. F. and sensible and latent heat while cooling and condensing between 50 and 10 deg. F. Let e = sensible heat removed in cooling from 70 to 50 deg. F. and j = total heat removed in cooling from 50 to 10 deg. F. Then $e_s = (s)\ (G)\ (\Delta\ t_2) = (0.258)\ (7{,}317)\ (70-50) = 37{,}800$ B.t.u. per hour. This value also can be obtained from the total heat curves by calculating the difference of the total heat at the original and final condition. Thus, the total heat of 49 per cent saturated air at 70 deg. F. = $h_{t70} - (1 - 0.49)\ h_{s70} = 62.2 - 0.51 \times 45.4 = 39.0$ B.t.u. per pound dry air; and total heat of saturated air at 50 deg F. = 33.8 B.t.u. per pound dry air. Therefore, heat to be removed = 39.0 − 33.8 = 5.2 B.t.u. per pound dry air. Thus, the total sensible heat to be removed in cooling to 50 deg. F. is $5.2 \times 7{,}317 = 38{,}000$ B.t.u. per hour. The discrepancy between the value calculated by the use of the humid heat and the total heat curves is due to the error involved in reading the charts. Also, $j = (h_{t50} - h_{t10})\ g = (33.8 - 6.4)\ (7{,}317) = 200{,}500$ B.t.u. per hour.

Fig. 1—Linkage energy chart for calculating specific heats of organic vapors in conjunction with Eq. (20) in text

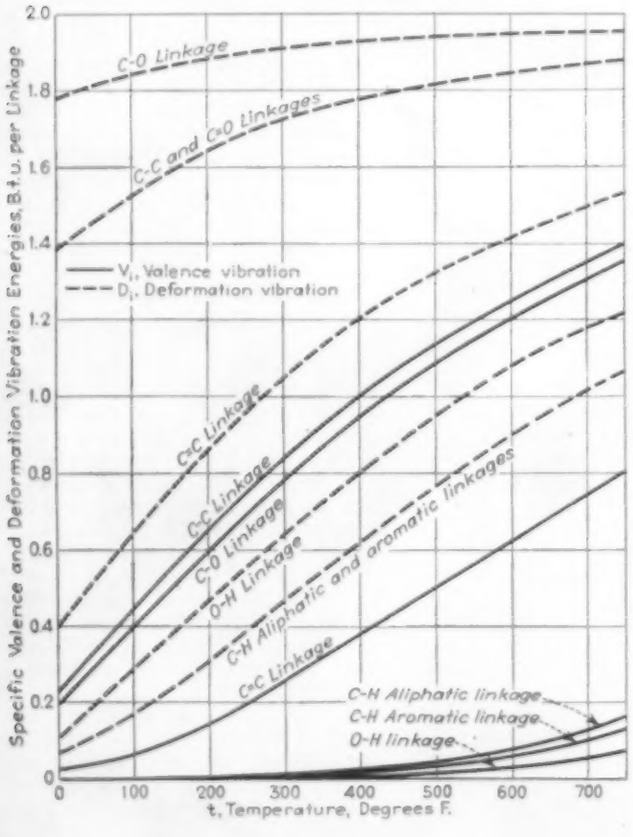
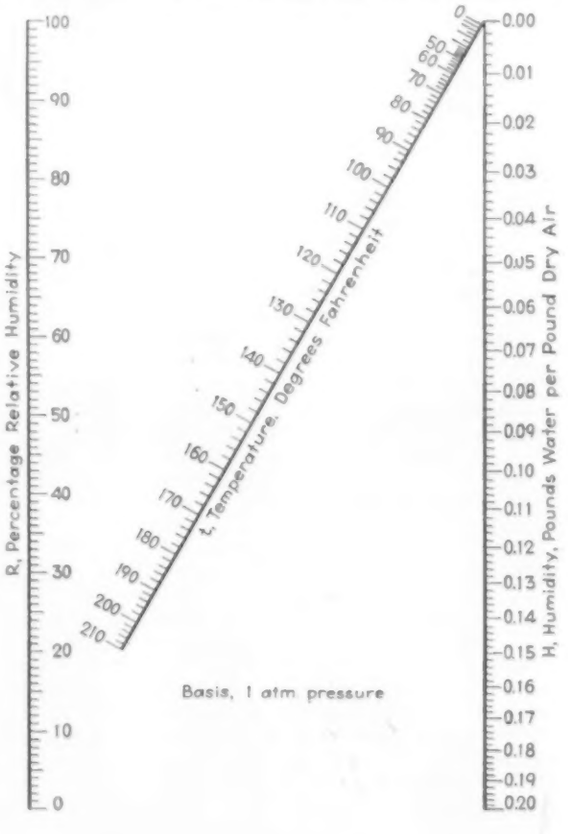


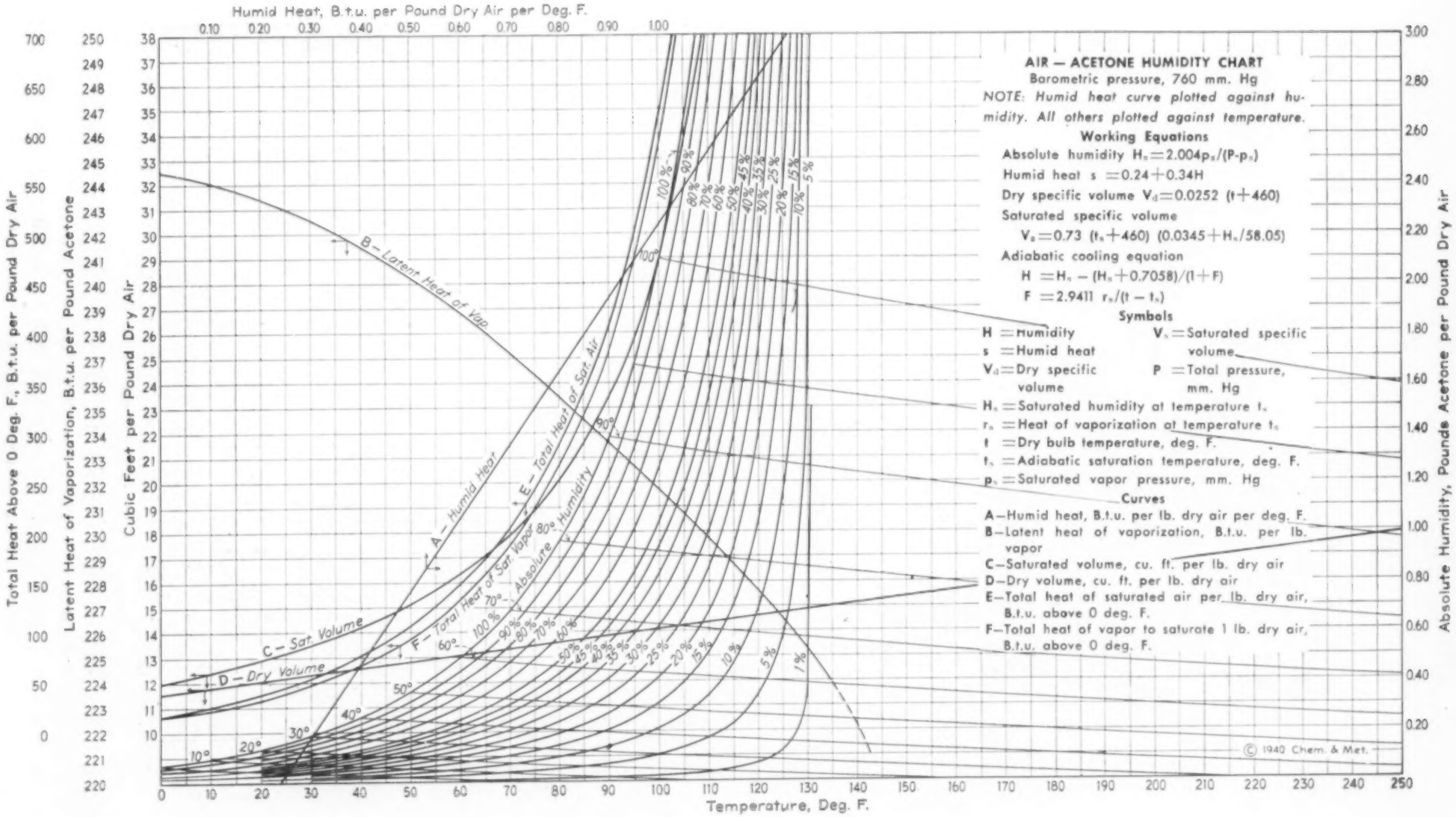
Fig. 2—Nomograph for interconversions between per cent relative and absolute humidity for air-water vapor mixtures


R, Percentage Relative Humidity
t, Temperature, Degrees Fahrenheit
H, Humidity, Pounds Water per Pound Dry Air
Basis, 1 atm. pressure

AIR-SOLVENT VAPOR PSYCHROMETRIC CHARTS

By E. J. Barta and H. J. Garber

CHEMICAL & METALLURGICAL ENGINEERING, MAY 1940



AIR — ACETONE HUMIDITY CHART

Barometric pressure, 760 mm. Hg

NOTE: Humid heat curve plotted against humidity. All others plotted against temperature.

Working Equations

Absolute humidity $H_s = 2.004 p_s/(P-p_s)$

Humid heat $s = 0.24 + 0.34H$

Dry specific volume $V_d = 0.0252\ (t+460)$

Saturated specific volume

$V_s = 0.73\ (t_s+460)\ (0.0345 + H_s/58.05)$

Adiabatic cooling equation

$H = H_s - (H_s + 0.7058)/(1+F)$

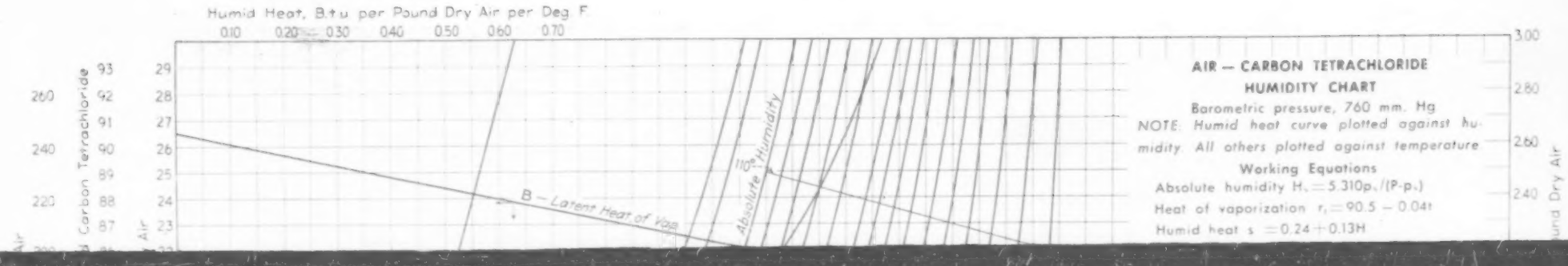
$F = 2.9411\ r_s/(t - t_s)$

Symbols

H = Humidity
s = Humid heat
V_d = Dry specific volume
V_s = Saturated specific volume
P = Total pressure, mm. Hg
H_s = Saturated humidity at temperature t_s
r_s = Heat of vaporization at temperature t_s
t = Dry bulb temperature, deg. F.
t_s = Adiabatic saturation temperature, deg. F.
p_s = Saturated vapor pressure, mm. Hg

Curves

A—Humid heat, B.t.u. per lb. dry air per deg. F.
B—Latent heat of vaporization, B.t.u. per lb. vapor
C—Saturated volume, cu. ft. per lb. dry air
D—Dry volume, cu. ft. per lb. dry air
E—Total heat of saturated air per lb. dry air, B.t.u. above 0 deg. F.
F—Total heat of vapor to saturate 1 lb. dry air, B.t.u. above 0 deg. F.


Humid Heat, B.t.u. per Pound Dry Air per Deg. F.
0.10 0.20 0.30 0.40 0.50 0.60 0.70
Latent Heat of Vaporization, B.t.u. per Pound Carbon Tetrachloride
Absolute Humidity, Pounds Carbon Tetrachloride per Pound Dry Air
B — Latent Heat of Vap.
Absolute Humidity

AIR — CARBON TETRACHLORIDE HUMIDITY CHART

Barometric pressure, 760 mm. Hg

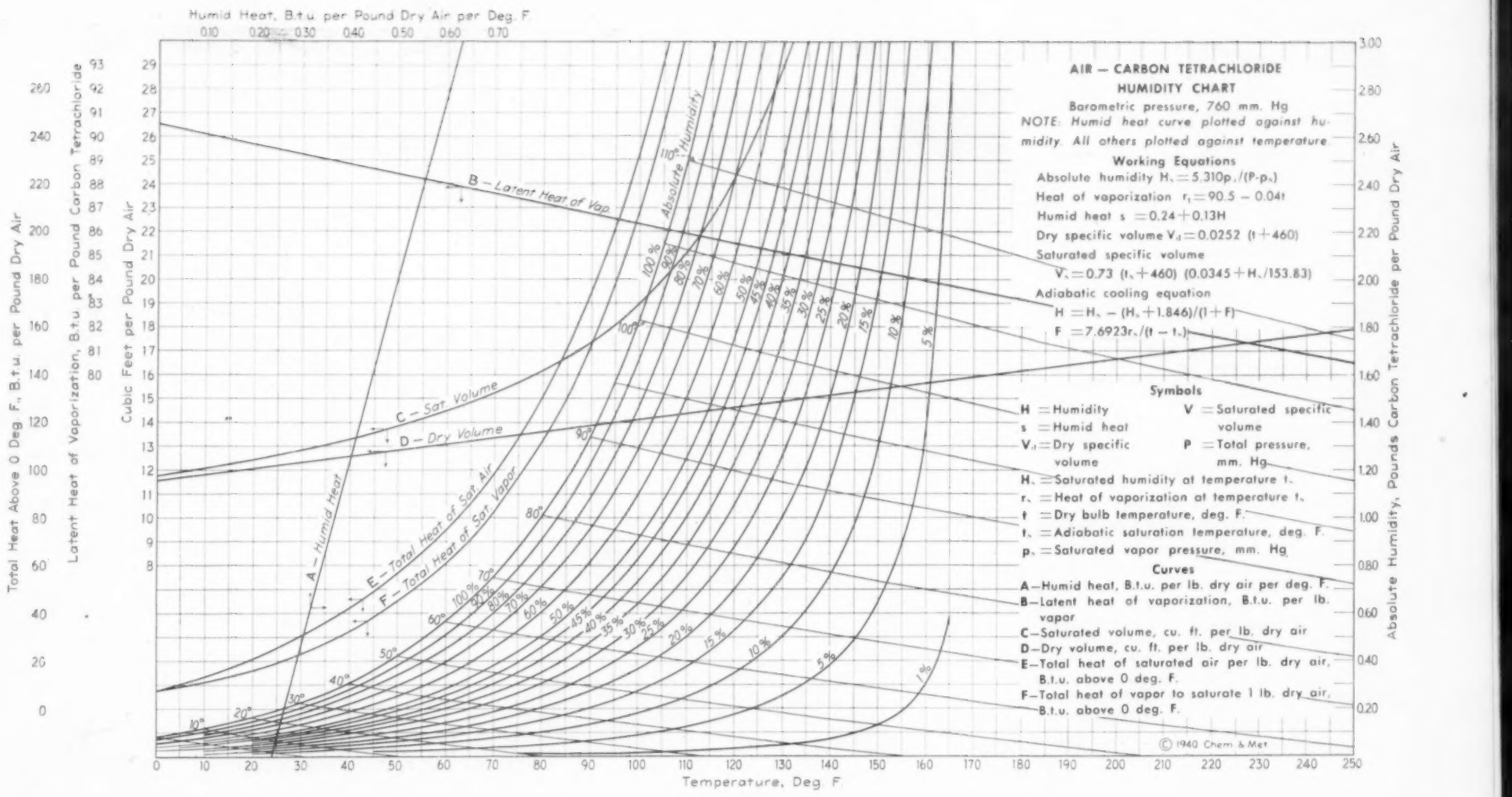
NOTE: Humid heat curve plotted against humidity. All others plotted against temperature

Working Equations

Absolute humidity $H_s = 5.310 p_s/(P-p_s)$

Heat of vaporization $r_s = 90.5 - 0.04t$

Humid heat $s = 0.24 + 0.13H$


Humid Heat, B.t.u. per Pound Dry Air per Deg. F
0.10 0.20 0.30 0.40 0.50 0.60 0.70
Total Heat Above 0 Deg. F., B.t.u. per Pound Dry Air
Latent Heat of Vaporization, B.t.u. per Pound Carbon Tetrachloride
Cubic Feet per Pound Dry Air
Absolute Humidity, Pounds Carbon Tetrachloride per Pound Dry Air
Temperature, Deg. F
A — Humid Heat
B — Latent Heat of Vap.
C — Sat. Volume
D — Dry Volume
E — Total Heat of Sat. Air
F — Total Heat of Sat. Vapor
Absolute Humidity
AIR — CARBON TETRACHLORIDE
HUMIDITY CHART
Barometric pressure, 760 mm. Hg
NOTE: Humid heat curve plotted against humidity. All others plotted against temperature.
Working Equations
Absolute humidity $H_s = 5.310p_s/(P-p_s)$
Heat of vaporization $r_t = 90.5 - 0.04t$
Humid heat $s = 0.24 + 0.13H$
Dry specific volume $V_d = 0.0252\ (t+460)$
Saturated specific volume
$V_s = 0.73\ (t_s+460)\ (0.0345+H_s/153.83)$
Adiabatic cooling equation
$H = H_s - (H_s+1.846)/(1+F)$
$F = 7.6923r_s/(t-t_s)$
Symbols
H = Humidity
s = Humid heat
V_d = Dry specific volume
V = Saturated specific volume
P = Total pressure, mm. Hg
H_s = Saturated humidity at temperature t_s
r_s = Heat of vaporization at temperature t_s
t = Dry bulb temperature, deg. F.
t_s = Adiabatic saturation temperature, deg. F.
p_s = Saturated vapor pressure, mm. Hg
Curves
A—Humid heat, B.t.u. per lb. dry air per deg. F.
B—Latent heat of vaporization, B.t.u. per lb. vapor
C—Saturated volume, cu. ft. per lb. dry air
D—Dry volume, cu. ft. per lb. dry air
E—Total heat of saturated air per lb. dry air, B.t.u. above 0 deg. F.
F—Total heat of vapor to saturate 1 lb. dry air, B.t.u. above 0 deg. F.
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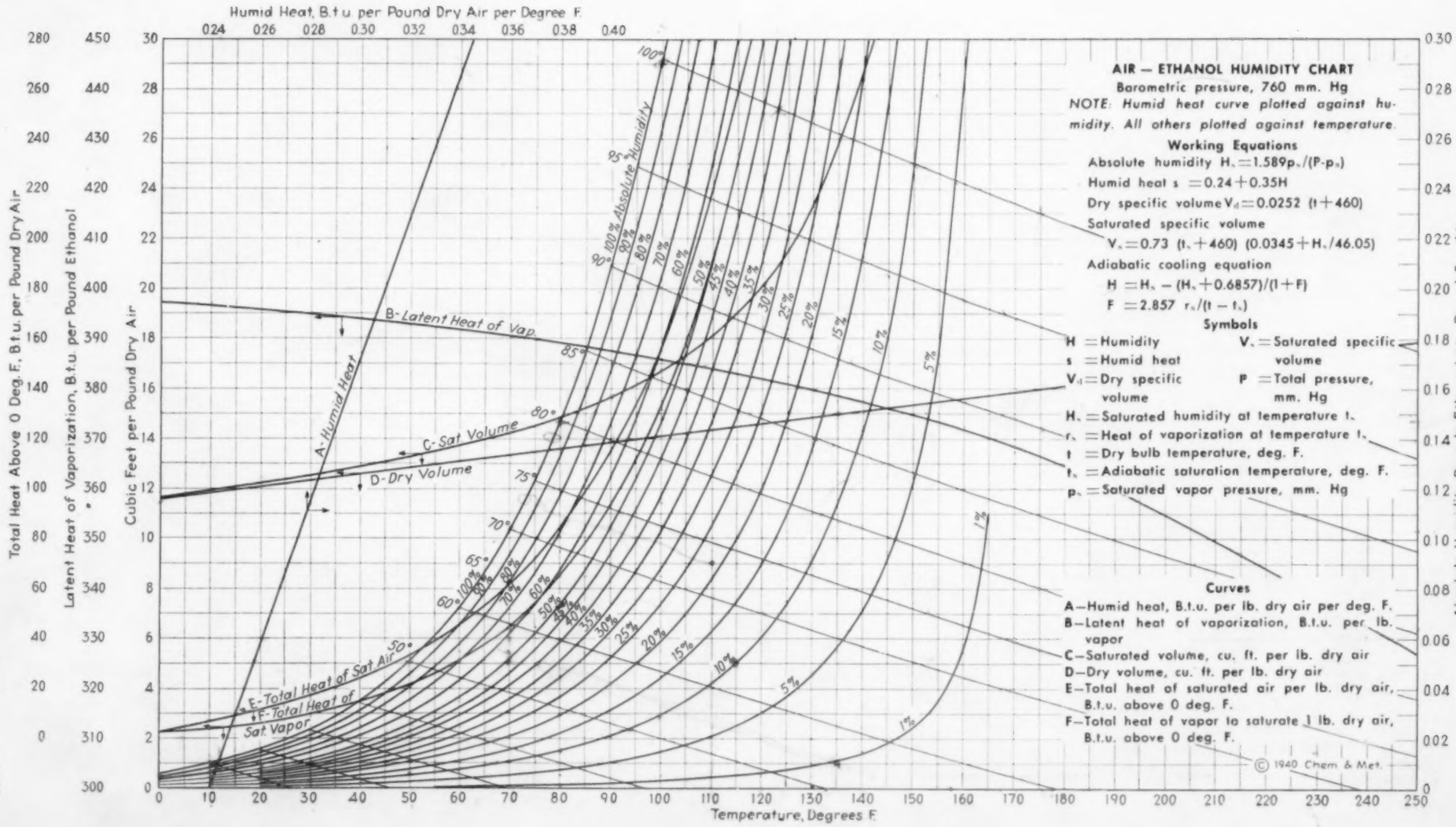
Humid Heat, B.t.u. per Pound Dry Air per Degree F.
024 026 028 030 032 034 036 038 040
Total Heat Above 0 Deg. F., B.t.u. per Pound Dry Air
Latent Heat of Vaporization, B.t.u. per Pound Ethanol
Cubic Feet per Pound Dry Air
Absolute Humidity, Pounds Ethanol per Pound Dry Air
Temperature, Degrees F.
A-Humid Heat
B-Latent Heat of Vap.
C-Sat Volume
D-Dry Volume
E-Total Heat of Sat Air
F-Total Heat of Sat Vapor
Absolute Humidity
AIR — ETHANOL HUMIDITY CHART
Barometric pressure, 760 mm. Hg
NOTE: Humid heat curve plotted against humidity. All others plotted against temperature.
Working Equations
Absolute humidity $H_s = 1.589 p_s/(P-p_s)$
Humid heat $s = 0.24 + 0.35H$
Dry specific volume $V_d = 0.0252\ (t+460)$
Saturated specific volume
$V_s = 0.73\ (t_s+460)\ (0.0345+H_s/46.05)$
Adiabatic cooling equation
$H = H_s - (H_s+0.6857)/(1+F)$
$F = 2.857\ r_s/(t-t_s)$
Symbols
H = Humidity
s = Humid heat
V_d = Dry specific volume
V_s = Saturated specific volume
P = Total pressure, mm. Hg
H_s = Saturated humidity at temperature t_s
r_s = Heat of vaporization at temperature t_s
t = Dry bulb temperature, deg. F.
t_s = Adiabatic saturation temperature, deg. F.
p_s = Saturated vapor pressure, mm. Hg
Curves
A—Humid heat, B.t.u. per lb. dry air per deg. F.
B—Latent heat of vaporization, B.t.u. per lb. vapor
C—Saturated volume, cu. ft. per lb. dry air
D—Dry volume, cu. ft. per lb. dry air
E—Total heat of saturated air per lb. dry air, B.t.u. above 0 deg. F.
F—Total heat of vapor to saturate 1 lb. dry air, B.t.u. above 0 deg. F.
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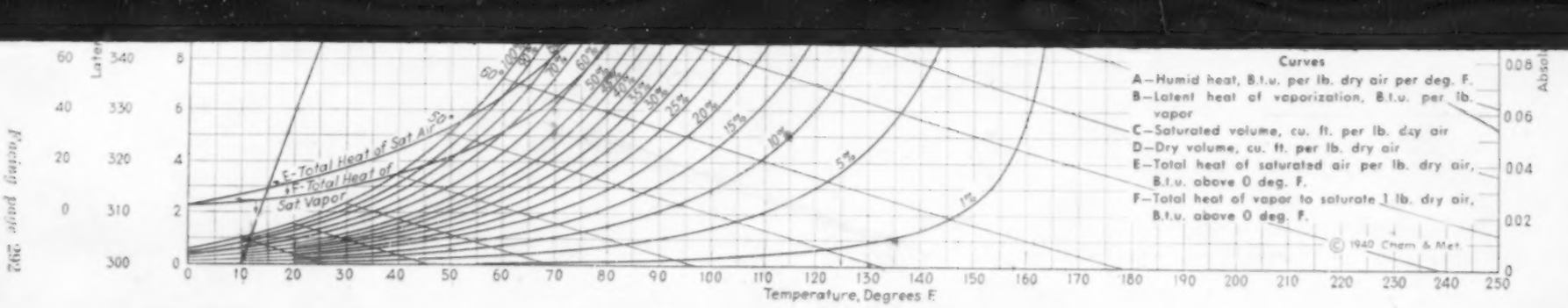
Curves
A—Humid heat, B.t.u. per lb. dry air per deg. F.
B—Latent heat of vaporization, B.t.u. per lb. vapor
C—Saturated volume, cu. ft. per lb. dry air
D—Dry volume, cu. ft. per lb. dry air
E—Total heat of saturated air per lb. dry air, B.t.u. above 0 deg. F.
F—Total heat of vapor to saturate 1 lb. dry air, B.t.u. above 0 deg. F.
E-Total Heat of Sat Air
F-Total Heat of Sat Vapor
Temperature, Degrees F
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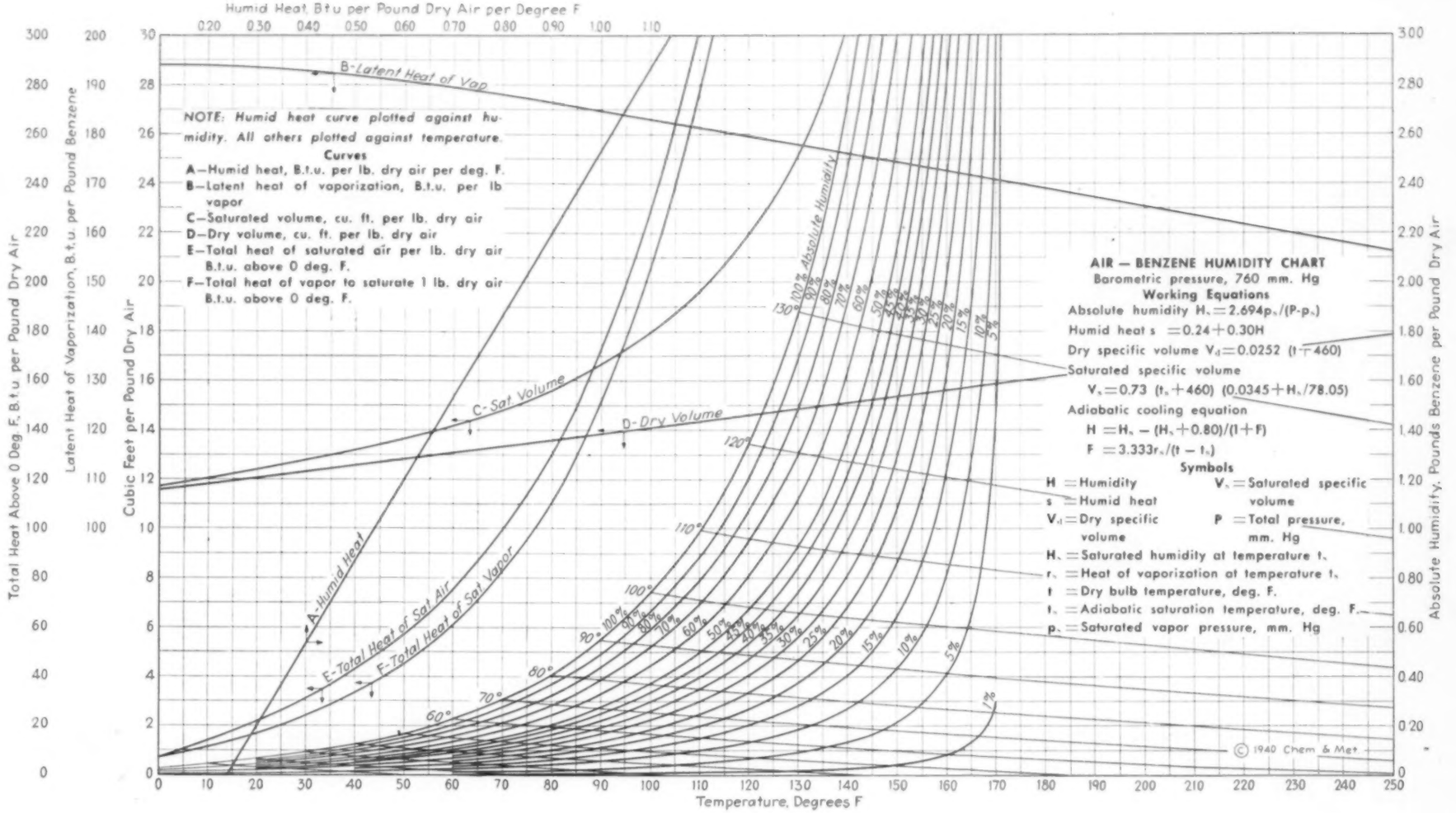
Humid Heat, Btu per Pound Dry Air per Degree F
B-Latent Heat of Vap
NOTE: Humid heat curve plotted against humidity. All others plotted against temperature.
Curves
A—Humid heat, B.t.u. per lb. dry air per deg. F.
B—Latent heat of vaporization, B.t.u. per lb vapor
C—Saturated volume, cu. ft. per lb. dry air
D—Dry volume, cu. ft. per lb. dry air
E—Total heat of saturated air per lb. dry air B.t.u. above 0 deg. F.
F—Total heat of vapor to saturate 1 lb. dry air B.t.u. above 0 deg. F.
C-Sat Volume
D-Dry Volume
A-Humid Heat
E-Total Heat of Sat Air
F-Total Heat of Sat Vapor
Absolute Humidity
AIR — BENZENE HUMIDITY CHART
Barometric pressure, 760 mm. Hg
Working Equations
Absolute humidity $H_s = 2.694p_s/(P-p_s)$
Humid heat $s = 0.24 + 0.30H$
Dry specific volume $V_d = 0.0252\ (t + 460)$
Saturated specific volume
$V_s = 0.73\ (t_s + 460)\ (0.0345 + H_s/78.05)$
Adiabatic cooling equation
$H = H_s - (H_s + 0.80)/(1 + F)$
$F = 3.333r_s/(t - t_s)$
Symbols
H = Humidity
s = Humid heat
V_d = Dry specific volume
V_s = Saturated specific volume
P = Total pressure, mm. Hg
H_s = Saturated humidity at temperature t_s
r_s = Heat of vaporization at temperature t_s
t = Dry bulb temperature, deg. F.
t_s = Adiabatic saturation temperature, deg. F.
p_s = Saturated vapor pressure, mm. Hg
Total Heat Above 0 Deg. F, B.t.u per Pound Dry Air
Latent Heat of Vaporization, B.t.u. per Pound Benzene
Cubic Feet per Pound Dry Air
Absolute Humidity, Pounds Benzene per Pound Dry Air
Temperature, Degrees F
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The total removed from the air is therefore 37,800 + 200,500 = 238,500 B.t.u. per hour.

This answer can also be obtained directly from the chart in one step by calculating the difference in the total heat of the 49 per cent saturated air at 70 deg. F. and the total heat of the saturated air at 10 deg. F. or $j = 7{,}317\ (39.0 - 6.4) = 238{,}500$ B.t.u. per hour.

Solution to (*f*)—The humidity of the air remains constant during the reheating of the air to its original temperature of 135 deg. F. Sensible heat alone is transferred to the extent of: $e_h = (s)\ (g)\ (\Delta t_h) = (0.2435)\ (7{,}317)\ (135\text{–}10) = 222{,}700$ B.t.u./hr.

Solution to (*g*)—The absolute humidity of the air changes from 0.051 to 0.010 while passing through the cooling-condensing system and since no air is lost or gained by the system then the quantity of ethanol condensed must be equal to that evaporated in the dryer or $W_e = g\ (\Delta\ H) = (7{,}317)\ (0.051 - 0.010) = 300$ lb. per hour.

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Types of Psychrometric Charts

By EDITORIAL STAFF. **A number of psychrometric charts have been analyzed to determine their similarities and differences, advantages and disadvantages. Thirteen typical charts are presented in skeleton form to facilitate the comparison and show how the various psychrometric properties are found from them.**

ANY AIR-WATER MIXTURE has five fundamental properties — temperature, moisture content, heat content, volume and pressure. All of these are generally considered in drawing psychrometric charts. Since most charts are drawn for atmospheric pressure, the factor of pressure may be eliminated. Certain combinations of these properties take on special importance. Air-water conditions, then, which may be expressed on a psychrometric chart are as follows:

1. Temperature
2. Moisture content (or vapor pressure)
3. Heat content
4. Equilibrium condition
5. Adiabatic cooling paths or evaporation paths
6. Volume

By temperature is meant, of course, the dry bulb temperature of the air-water mixture as measured with an ordinary thermometer. All charts use this property.

Moisture content may be expressed as pounds or grains of water per pound of dry air or as pounds or grains of water per cu.ft. of air. The moisture content may also be defined by the vapor pressure of the moisture. Most charts intended for use in chemical engineering calculations use the first-named unit. The volume base is seldom employed and the vapor pressure scale is usually a supplementary scale. Dew-point temperatures are often shown on the humidity scale.

Four kinds of heat measurements are shown on the psychrometric chart —sensible, latent, total and humid heat. Sensible heat is the change in heat content brought about by a change in temperature alone. Therefore it is often measured along the temperature scale at constant humidity. Latent heat is the change of heat content produced by change in moisture content. This quantity appears on most charts merely as a part of the total heat; however, some charts show a plot of heat of evaporation against temperature. Total heat (sum of sensible and latent heats) will be discussed later. Humid heat is nothing more than the specific heat of the air-water mixture and increases with humidity ($C_p = 0.238 + 0.48\ H$). Many charts carry a separate curve for it.

The equilibrium condition is shown by the saturation curve, and it is an important feature of every chart. There are two systems of showing partial saturation (i.e. degree of superheat) —per cent relative humidity and percentage absolute humidity. The former is a ratio of the partial pressure of the water vapor in the mixture to the vapor pressure of water (same as partial pressure in saturated air) at the same temperature. Percentage absolute humidity is the ratio of the weight of water vapor accompanying a pound of dry air to the weight of water vapor that would accompany a pound of dry air when saturated at the same temperature.

Both these systems are used extensively and if used incorrectly they can result in serious errors either in making or using a chart. To complicate the situation some chart makers have named the lines on their charts incorrectly. Others have used an indefinite term (such as *percentage of humidity*) which does not indicate either system. Therefore, the user of a psychrometric chart should determine for himself whether per cent relative humidity or percentage absolute was used for plotting the chart. Fortunately one may be substituted for the other in the low temperature ranges—up to 80 deg. F.—without serious error. However, at higher temperatures the error may become quite large.

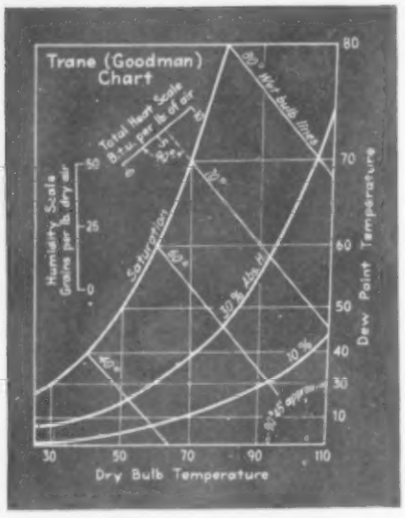
At a temperature of 212 deg. F. (at atmospheric pressure) strange things begin to happen to the humidity concept. The humidity at saturation obviously becomes infinite because water can evaporate for any length of time without reaching a saturation point. Percentage humidity lines as well as the saturation line then become asymptotic to the 212 deg. temperature line. Then at 212 any sample of air has zero percentage absolute humidity.

Relative humidity on the other hand has a finite value at 212 deg. and at higher temperatures. Again the saturation line is asymptotic to the 212 deg. line. But the per cent R.H. lines cross the 212 line and become asymptotic to the temperature line representing saturation at a pressure of 14.7 divided by R.H. (lb. per sq.in.). (See page 296 for full explanation.)

Almost every chart has wet-bulb temperature lines (more correctly called evaporation lines). If not, it may have adiabatic cooling lines. Some charts have both. Theoretically these two paths do not coincide. They differ by a slight amount due to the heat of the liquid water. However, in practice, they are generally assumed to be coincident for air-water mixtures at low temperatures. This is one approximation made on most charts. In those cases where the lines are parallel or nearly parallel, an evenly divided total heat scale may be applied at right angles to measure the difference in heat content between various adiabatic lines. This method is accurate where adiabatic lines are used and are parallel. Otherwise, it involves a slight amount of error.

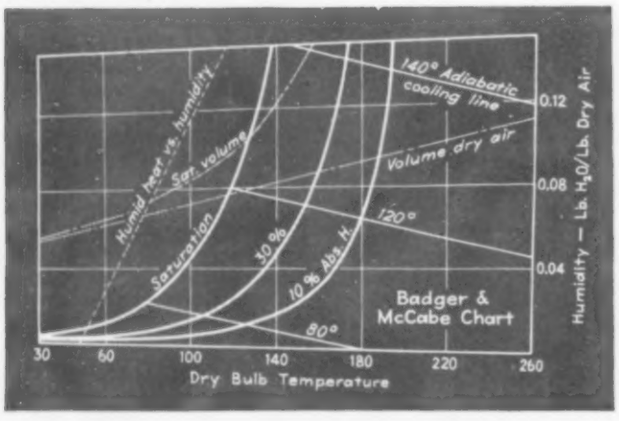
Not all charts carry an indication of volume. Those that do use two different methods. Either volume lines cross the chart at intervals so they can be read directly as any other properties of the mixture; or they constitute a separate plot superimposed over the whole chart. Instead of volume, *PV* lines may be plotted. However, they are of little significance unless saturation curves for various pressures are given. Most charts are drawn for atmospheric pressure thus eliminating the pressure consideration.

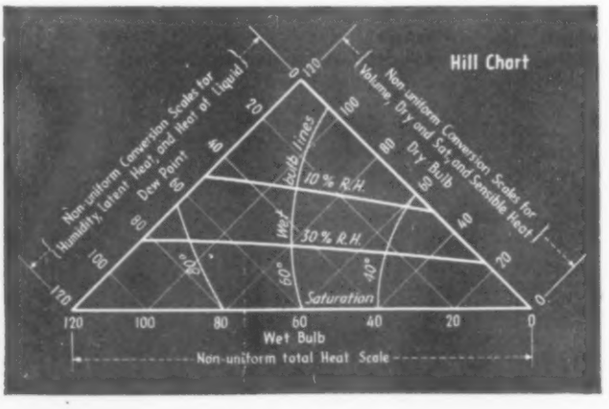
Grosvenor Chart—In 1908 William Grosvenor introduced new principles to

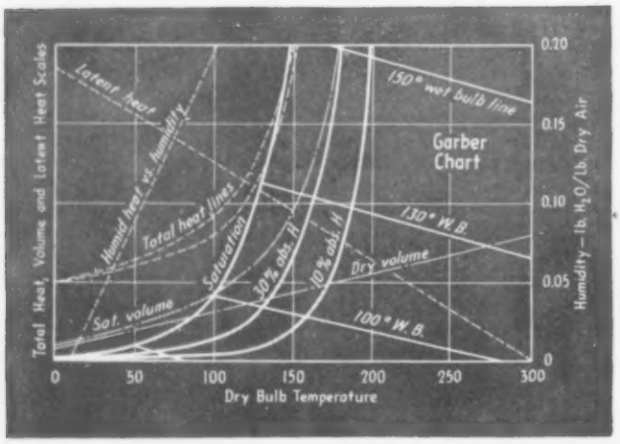


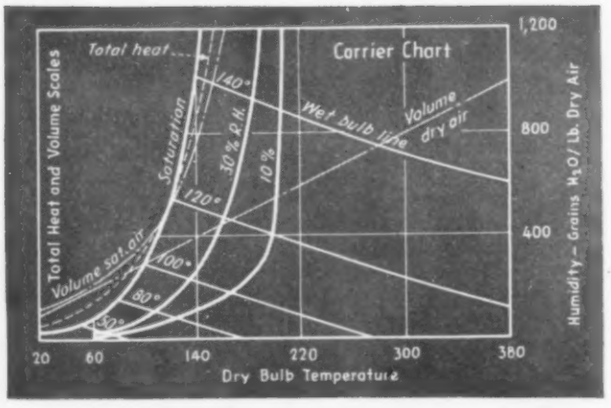
the plotting of psychrometric charts. He first used the pounds-of-water-per-pound-of-dry-air humidity concept and percentage absolute humidity curves rather than relative humidity curves. His has since been called the "chemical engineer's system" as contrasted with the "mechanical engineer's system." Grosvenor's chart plots temperature against humidity, has a high temperature range and is designed primarily for drying calculations rather than air conditioning. One curve on the original chart which is not reproduced in the accompanying drawing is humid heat vs. temperature. More recent charts include humid heat vs. humidity which is a straight line relation.

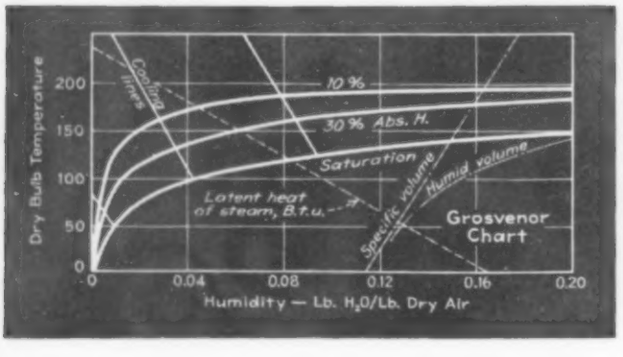
Garber Chart—Many modifications of the Grosvenor chart have been published since 1908. Lavine and Sutherland (see *Chem. & Met.*, April 1928, p. 226) used the now conventional arrangement of temperature as abscissa and humidity as ordinates. Their's was even a higher range chart going up to 680 deg. F. In the first edition of their chemical engineering text, Walker, Lewis and McAdams published the same type of chart using a lower temperature range suitable for air conditioning as well as drying calculations. (In their new edition, these authors have used a relative humidity type of chart.) One of the most recent charts of this type available in large size is the Garber chart, shown herewith. It too plots temperature as abscissa and humidity as ordinates. The original has scales for both pounds and grains of water per pound of dry air as well as a nomograph for conversion from humidity to relative humidity. It also has an improvement

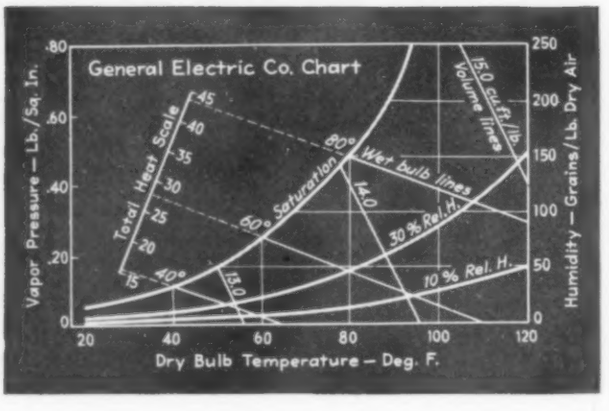










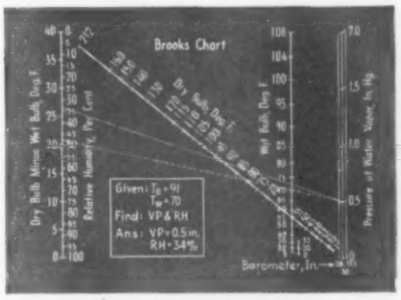


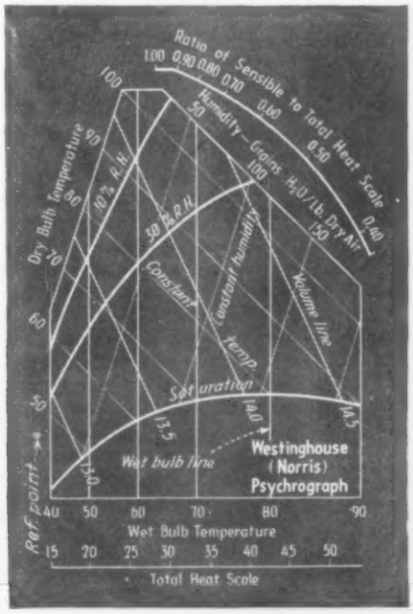
over the Grosvenor chart in the form of a total heat scale. However, this property must be read from a supplementary curve rather than from the chart itself. An important advantage of all the charts described in this paragraph is that a line drawn between two points on the chart represents all conditions which may result from the mixing of air at the two different initial conditions. This situation will obtain on any chart where temperature and humidity are measured on evenly divided scales.

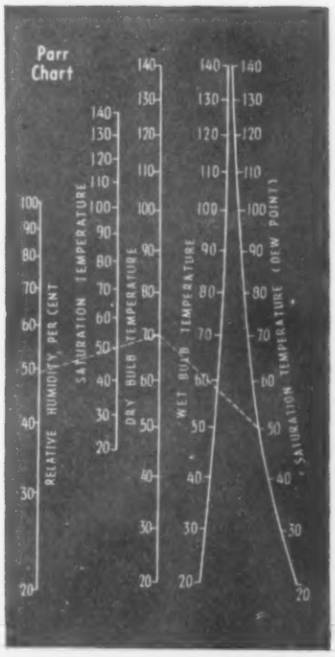
Badger and McCabe—An accompanying sketch is taken from the humidity chart in Badger and McCabe's chemical engineering text. On this chart the axes (temperature and humidity) have been tilted slightly to make the adiabatic cooling lines straight and parallel. Wet-bulb temperatures then become approximate; however, they are close enough for any practical purpose. This arrangement enables easy scaling of total heat, a fact of which Badger and McCabe have not taken advantage.

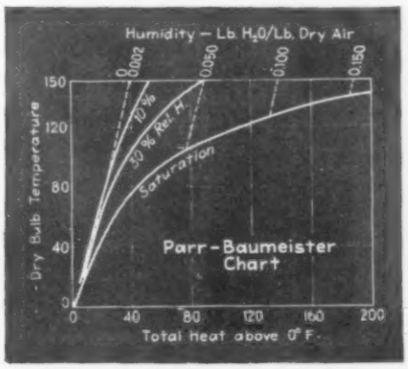
Goodman Chart—Another chart which follows the Grosvenor system for low temperatures is the Trane Co. chart, developed by William Goodman. By means of a number of minor compromises and approximations, this chart reduces the labor of making air conditioning calculations to a minimum. It plots dry bulb temperature against dewpoint temperatures. The chart is used in conjunction with a transparent ruler with a number of auxiliary scales. Dry bulb temperature lines diverge toward the top of the chart so that sensible heat can be measured horizontally. The dewpoint scale is not evenly divided in order that the humidity scale may be evenly divided and vertical. Wet bulb lines are almost parallel due to a compromise with dry bulb lines. Total heat may be measured perpendicular to the wet bulb lines on an evenly divided scale. The chart has the outstanding advantage that a straight line between two points not only represents intermediate conditions but its slope indicates the ratio of sensible to total heat change, a property which can be obtained only by using uniform scales for both sensible and total heat. Volume is determined from a separate plot. In spite of its approximations this chart produces surprisingly accurate results.

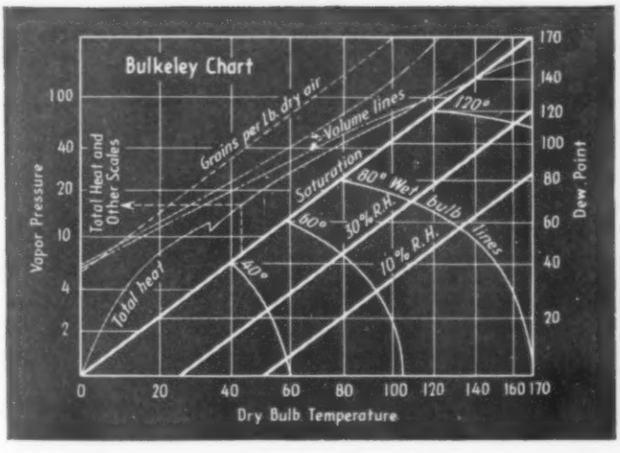
Carrier and G-E—Now we come to the charts that express partial saturation (i.e., degree of superheat) in terms of per cent relative humidity rather than percentage absolute humidity. Oldest among them is the Carrier chart shown herewith. Carrier charts are available for both low and high temperature ranges. This type of chart has the advantage that all its scales are conventional and straight-forward, enabling easy reading and interpolation. The General Electric chart (also shown in the cut) is similar with modifications. The total heat scale and volume lines have been

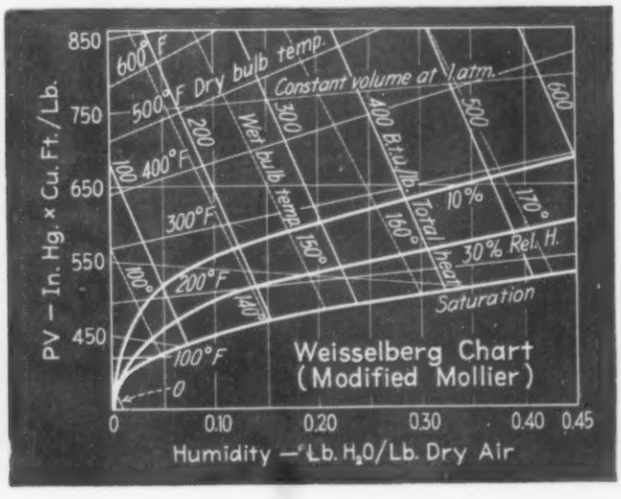












applied directly to the chart eliminating the reference curve usually employed.

The Parr-Baumeister chart (see cut) is an interesting variation of this type chart. It is a plot of temperature against total heat. This results in humidity lines that are straight but not quite parallel and at an odd angle with temperature. When this chart is turned over, it is evident that it is merely a Carrier-type chart with the humidity lines displaced to make the total heat lines come out at right angles to temperature. Its principal disadvantage is low visability in the low temperature ranges.

Westinghouse Chart—At this point let us introduce the Westinghouse Psychrograph developed by A. M. Norris. It is a queer-looking plot of total heat against sensible heat (see cut). The total heat lines are virtually vertical while the sensible heat lines have been placed at an angle and are labeled with the corresponding dry-bulb temperatures. Theoretically the dry bulb lines should curve slightly due to changes in specific heat, but this has been neglected with consequent slight error. Straight humidity lines and curved per cent relative humidity lines are included. The advantage of the chart is that the slope of a line drawn between two points represents the ratio of sensible to total heat change (as in Trane chart). The slope of this line can be found by connecting the reference point at lower left with the proper heat ratio on the curved scale at upper right.

Bulkeley and Hill—All the above charts have a curved saturation line. Two charts that do not are the Bulkeley and Hill charts. The former is an empirical chart based on the premise of straight and parallel lines for saturation and relative humidity. As a result all scales are non-uniform. The vapor pressure scale is approximately logarithmic; the temperature scale is nearly a reciprocal scale. Total heat and humidity in various units are all read from the vapor pressure scale by means of conversion curves. This is the chart reproduced in the A.S.H.V.E. Guide. On this chart the condition attained by two samples of air when mixed cannot be determined by drawing a straight line between the two initial points.

Dr. Hill's chart, although triangular in shape is quite similar to Bulkeley's. If it is turned so that the right angle is in the lower righthand corner, the similarity will be noted at once. The saturation line is straight. However the relative humidity lines are curved. Wet bulb lines are likewise curved. All sorts of values may be read from the chart by reference to tables along the axes. Tables rather than scales are used to facilitate reading inasmuch as all units are non-uniform. Straight lines do not represent mixing conditions.

Weisselberg Chart—Probably the most versatile of all psychrometric charts is the Weisselberg adaptation of the old Mollier air-water mixture chart. It is a plot of humidity against total heat with the total heat lines at an angle. A distinction is made between total heat and wet bulb lines. Temperature lines are straight but not parallel. Saturation curves are shown for pressures other than atmospheric. Constant PV lines constitute a feature not found on other charts. Upon using only atmospheric pressure, these lines, of course, become constant volume lines. A number of marginal lines (not shown on the cut) enable the user to determine the path of an air-water mixture when moisture of a known heat content is added, which is the same as the ratio of sensible to total heat change. An important consideration in using this chart is that total heats are based on zero at 32 deg. F. for *both* the moisture and the air. Most charts and tables use heat above 32 deg. F. for the moisture and above zero deg. F. for the air. Because of its broad range, this chart is particularly applicable to drying calculations.

Parr's and Brooks' nomographic psychrometric charts are pictured to illustrate the fact that the author has not attempted in this brief article to describe *all* the types of psychrometric charts. He has merely endeavored to point out the similarities and differences between some of the charts that have come to his attention.

A new type of chart where relative humidity lines may be plotted for various vapors with a slight amount of data has been developed by Othmer and is described below.

New Psychrometric Chart

By DONALD F. OTHMER, Polytechnic Institute, Brooklyn, N. Y. **This recently discovered method of plotting gas-vapor mixture data has marked advantages in simplicity and ease of plotting, especially where only scanty information is available. Its application to chemical dehydrating and solvent recovery is also considered.**

EITHER percentage absolute humidity or "percentage vapor pressure" (a term used by A. B. Newman in 1937) is only a means of specifying the amount of moisture in the air; the first is the relation to the weight of vapor in air at saturation, the second is the relation to the vapor pressure at saturation. Percentage humidity, on the pound per pound of dry air basis, obviously falls down completely at any temperature above the boiling point of water since at that temperature the number of pounds of water per pound of air at saturation is, of course, infinite. For problems in drying and elsewhere where temperatures higher than the boiling point of water are involved, there is thus no way of expressing the humidity on a percentage basis, and only "percentage vapor pressures" are valid. When other problems are to be handled concerned with solvents or other liquids and air or other gas or gases as the carrier, or such problems as those involving dehydration with an aqueous salt solution having a lower vapor pressure than water, the "percentage vapor pressure" system of specifying air conditions is also to be preferred.

It is interesting to show by a minor calculation what happens to the lines of per cent humidity and of per cent vapor pressure (relative humidity) at high temperatures. The equation relating the humidity of saturated air in pounds of moisture per pound of air (H) to the vapor pressure of water (P) in pounds per square inch is:

$$H = \frac{18}{29} \frac{P}{(14.7 - P)}$$

This is the equation of the saturation or 100 per cent line. Percentage humidity is the ratio on a per cent basis of the weight of water in the sample to the weight of water in saturated air. Hence the equation of a line of any constant per cent humidity (C) on a temperature-humidity plot is

$$H = C \frac{18}{29} \frac{P}{(14.7 - P)}$$

It is evident that no matter what the value of C is, the value of the expression $(14.7 - P)$ will still be zero and H will be infinite when P is equal to the normal atmospheric pressure of 14.7 lb. per sq.in. In other words, all per cent humidity lines are, therefore, asymptotic to the ordinate representing the normal boiling point of water.

On the other hand, the humidity at some given per cent vapor pressure (relative humidity) refers to the number of pounds of moisture per pound of air when the partial pressure of water vapor is the given per cent of the vapor pressure of water at the given temperature. The equation of a line of any constant per cent vapor pressure (relative humidity) C_1 thus becomes:

$$H = \frac{18}{29} \frac{C_1 P}{(14.7 - C_1 P)}$$

The value of H obviously becomes infinite where $C_1 P = 14.7$, i.e., where the partial pressure of water in the mixture becomes 14.7. Thus each per cent vapor pressure line becomes asymptotic to the dry bulb temperature ordinate where the vapor pressure of water is equal to 14.7 divided by

the per cent in question. This relation may also be expressed log P = log 14.7 − log C_1; and in the plot to be described wherein log pressures are used, the progressive displacement to the right of these ordinates when the lines become asymptotic follows a regular logarithmic order.

A useful and rapid method of plotting and using humidity and related charts may be developed from the method of plotting on log paper the vapor pressure of a liquid versus the vapor pressure of a standard material. This method, disclosed at the Buffalo meeting of the American Institute of Chemical Engineers by the writer and to be elaborated elsewhere, shows that the slopes of the straight lines so obtained are proportional to the molar latent heats of the liquids. It is general in its application to (1) the ordinary humidity chart of air and water or related charts for any volatile material and any carrier gas; (2) charts illustrating the depressed vapor pressure of salt solutions, etc., and their humidity relations with air; and (3) charts illustrating the air-vapor relationships where the vapor is a mixture of that from two or more volatile liquids.

Fig. 1 is a chart which has been plotted by this method for water and air. The additional lines associated with the usual humidity charts, such as those of the volume and of heat relations, may also be plotted on these coordinates; but it is felt that they unnecessarily complicate the picture and might better be presented as separate tables or plots. The material which should be included on a humidity chart includes the lines for percentage vapor pressures (relative humidities) plotted on a background using dry bulb temperatures for ordinates and pounds of moisture per pound of dry air as abscissa. The abscissas also represent dew point temperatures and may be calibrated as well to indicate vapor pressures. There should also be plotted the adiabatic saturation lines and these are, in the case of water, the wet bulb lines used in determination of humidity by wet and dry bulb thermometers and for other psychrometric problems. Of somewhat more interest is the fact that they are also lines of constant enthalpy and may be so calibrated directly as total heat above a standard reference temperature.

The drafting of this chart is not difficult:

1. A sheet of logarithmic paper has values for the vapor pressure of water indicated along the X-axis; and the temperatures corresponding to these vapor pressures are also indicated, thus giving a single line relating the vapor pressure and temperature. The vertical dry bulb temperature lines are drawn from these temperatures.

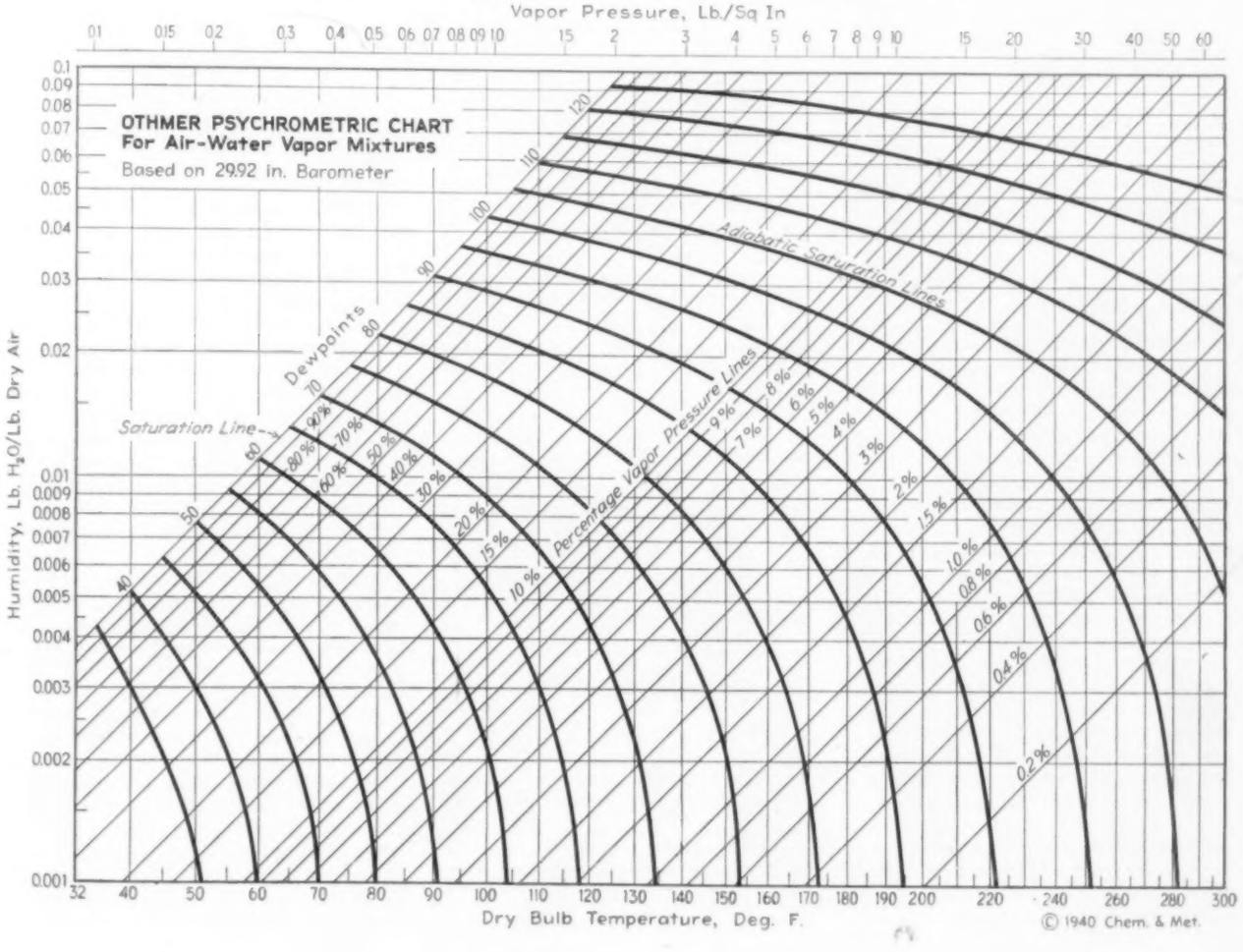
2. The Y-axis is calibrated for humidity in pounds of water per pound of dry air and the saturation line is plotted from tabulated data ("Perry's Handbook," etc.) or from Equation (1), i. e.,

$$H = \frac{Mv\,P}{Mc(14.7-P)} \qquad (1)$$

where P is vapor pressure in lb. per sq. inch, Mv is the molecular weight of vapor, and Mc is the molecular weight of the carrier gas (air in this case). For water and air this is $H = 18P/29(14.7-P)$. This saturation line is approximately straight and would be straight except for the volume considerations involved in the definition of humidity, wherein at the higher humidities the ratio of water to air increases extremely rapidly. The vapor pressure line would be straight and have an angle of 45 deg. if plotted with any desired pressure units on the Y-axis; and the saturation line departs only slightly from it in the usual range.

3. The lines of percentage vapor prespressure (relative humidity) are plotted exactly the same shape as the saturation line and at distances below laid off on the log scale according to the per cent. Thus the values are laid off on the 40 deg. F. ordinate so that the 90 per cent line intersects to give a value of 90 per cent as much humidity as the saturation value;

Fig. 1—Othmer log-plot psychrometric chart for water vapor and air



similarly for other temperatures and humidities. A template may be drawn for the saturation curve and repeated for each of the relative partial pressure curves; a series of straight lines may be used to define this; or a single straight line may be used at a slightly different angle than 45 deg. Any desired method for reproducing the saturation line within the limits of accuracy desired is satisfactory. The lines in Fig. 1 are drawn very slightly curved but may be drawn straight with an error of only about ± 1 per cent if temperatures no higher than 100 deg. F. are involved.

4. The lines of constant enthalpy, usually called the adiabatic saturation or cooling lines (for water they are also approximately the wet-bulb lines), are calculated from Equation (2), i. e.,

$$H = \frac{Ls\,Hs - So(t - ts)}{Sv(t - ts) + Ls} \qquad (2)$$

where H is humidity in pounds of vapor per pound of carrier gas at temperature t, ts is the saturation temperature, i. e., the point where the adiabatic cooling line intersects the saturation line, Hs is saturation humidity at ts and Ls is the latent heat of water in B.t.u. per pound, also at ts. So and Sv are the respective specific heats of the carrier gas and the vapor. For air the usual value is 0.24 and for water 0.48 in the usual range considered.

The Bulkeley chart (see p. 295, this issue.—Ed.) is drawn so as to resemble this chart but is empirically drawn and its construction for other materials than water and air would be tedious.

The data necessary for the plotting of a humidity or vapor-gas chart for any liquid and carrier gas using the method shown here are thus:

1. Vapor pressure values. (For this method of plotting, it will be shown that only two points on the vapor pressure curve are required.)

2. Latent heat data throughout the range in question. Due to the fact that the latent heat of the liquid may be immediately determined at any temperature by the fundamental relation of the slope of its vapor pressure line on the log plot against water (as developed at the Buffalo A.I.Ch.E. convention), these data may be readily obtained from the two or more vapor pressure determinations of (1).

3. The specific heats of the carrier gas and of the vapor of the liquid in temperature range considered.

When plotted by this relatively simple method using log paper as the background, not only are the minimum of data required but considerable accuracy for low values of humidities is obtained since, due to the ratio characteristics of log paper, an equal per cent of accuracy is experienced for low humidities as for high—which is, of course, not the case ordinarily.

Obviously no final chart can be more accurate than the data from which it is plotted; and vapor pressure, latent heat, and specific heat data, are probably not accurate for most substances closer than 1 or 2 per cent. A further slight inaccuracy is due to a minor assumption in the above formula always used for calculating the adiabatic cooling lines. This, coupled with the difficulty of obtaining even moderately accurate engineering data relative to the use of a humidity chart, indicates that some short cuts may be made in the plotting of a chart leading to errors of a few per cent as compared to the accurate plot of Fig. 1. Such a degree of accuracy is sufficiently close considering limitations of data and usage.

There are several methods of plotting these humidity charts:

I. A general humidity chart may be plotted which may be used as the background for any vapor in any carrier gas. (Fig. 2.)

1. The saturated line is drawn on log paper at 45 deg. and passing through 1.1; then 10,10; 100,100, etc. The relative partial pressure lines are then drawn parallel at the appropriate distance below, i. e. the 90 per cent line passes directly below at 0.9, the 80 per cent at 0.8, etc. This much represents *the humidity chart for any gas and vapor.*

2. The X- and Y-axis must next be calibrated for any particular combination of materials. Acetone and air will be used as an example. In working with such a flammable combination the vapor concentrations are usually kept below the lower limit of flammability, in this case about 2.89 per cent at 20 deg. C. (22 mm.). Thus, the only usable part of the range is that below a vapor pressure of 22 mm. The temperature scale (dry bulb temperatures) is laid off along the X-axis in the way already described using the vapor pressure curve of the material in question. If laid off also along the Y-axis, the corresponding abscissas are, of course, dew point lines in the familiar chart. A vapor pressure calibration may also be retained.

In some cases, only a relatively small number of vapor pressure determinations are available for the range to be plotted, as, for example, for acetone at low temperatures. The dry bulb temperature scale may be filled in by making use of a corollary of the log method of plotting vapor pressures as follows: Any liquid whose vapor pressures at regular temperature intervals are accurately known in the range to be considered has its vapor pressure-temperature scale laid off on the Y-axis and the straight line corresponding to its vapor pressure in reference to that of the original liquid is drawn between the corresponding few points for that material. Ammonia was chosen; the temperature scale corresponding to vapor pressures was laid off on the Y-axis, and the vapor pressure line drawn. The numerous points of temperature from the Y-axis were projected to the right until intersections were reached with the straight vapor pressure line; and these intersections were then projected down to the Y-axis to give a calibration of as many points of temperature as desired.

3. The lines for every percentage vapor pressure (relative humidity) having thus been drawn and the corresponding dry bulb temperatures, saturation temperatures, dew point lines, and lines of constant vapor pressure having thus been obtained, it is necessary also to calibrate the Y-axis in terms of humidities in pounds per pound of carrier gas. This may be done empirically as in the case of the Bulkeley chart by calculating various humidities corresponding to pressures along the saturation curve and indicating these values along the Y-axis. In this case there is no relation between the values of pressure and humidity. In the usual case, however, where only a relatively small total pressure of liquid is experienced, i. e., less than 10 per cent, another method may be used which will give results well within the accuracy of the vapor pressure, latent heat, specific heat, and other values used. The value for the humidity is calculated from Equation (1) above for the mid-temperature on the saturation line; and the ratio between the number of pounds per pound of carrier gas and the vapor pressure in whatever units used is obtained. This value is then used as a constant factor for the calibration of the lines of constant humidity and in fact results in the simple movement of the logarithmic scale of the Y-axis up or down because, of course, such vertical addition of distance along any ordinate is equivalent to the multiplication of values on that ordinate by the constant factor.

II. Another method is useful also where only low total pressures of liquid are encountered. The log sheet has the appropriate dry bulb temperatures calibrated on the X-axis according to the vapor pressure curve of the liquid. The correction factor for humidities in relation to the vapor pressures is obtained, as before, from the mid-point of temperature to be plotted on the saturation line. The Y-axis is then calibrated in humidities; and the constant is multiplied by the vapor pressures at the several dry bulb temperatures; the points being plotted to give a saturation line which is, of course, straight. The lines of per cent vapor pressure (relative humidity) are plotted directly below at the correct distances, the same as before.

III. Still another method of plotting, that used for Fig. 1, has been described above and does not involve the slight inaccuracies of the above two methods in the use of a constant ratio between vapor pressure and humidities.

In all of the above cases the adiabatic cooling lines or lines of constant enthalpy are calculated and plotted in the same way as mentioned above for Fig. 1.

Dehydrating Solutions

In the case of salts or other nonvolatile materials dissolved in water, the relative partial pressure of water is lowered. The practical utilization of this phenomenon is in dehydration by means of a spray of such an aqueous solution. In this case each solution when in contact with air will have a definite vapor pressure at every temperature and this relation is the basis of a distinct 100 per cent vapor pressure line (saturation) line for each different concentration. These several saturation lines for different concentrations will all fall below the water saturation line and will become lower as the concentration is increased.

In dealing with some solutions, such as those of common salt, the several vapor pressure lines for different concentrations are straight and parallel to that of water, hence these saturation lines at different concentrations will fall in the same positions and have the same shape as the percentage vapor pressure (relative humidity) lines. They have a vapor pressure of water which is lower by the same amount throughout the entire temperature range; and it follows from the log plot theory that there is no appreciable heat of solution, i.e., the latent heat of the water evaporated from the solution is substantially the same as that of water out of pure water.

Solutions of calcium chloride of various concentrations have vapor pressures which, on the log plot, give a sheaf of straight lines. The slopes of these lines, multiplied by the latent heat of water at any given temperature, give the latent heat of water from the solution at this same temperature. This latent heat from solution includes, of course, the heat of dilu-

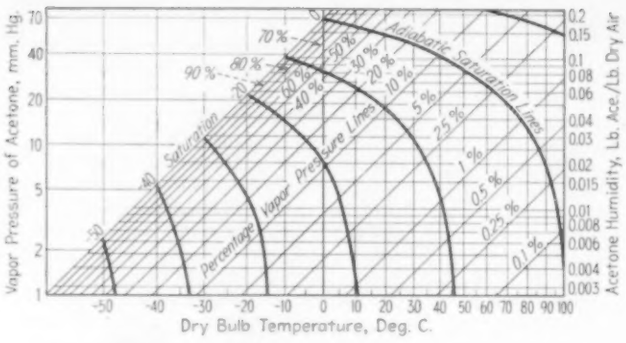

Vapor Pressure of Acetone, mm. Hg.
Acetone Humidity, Lb. Ace./Lb. Dry Air
Dry Bulb Temperature, Deg. C.
Saturation
Percentage Vapor Pressure Lines
Adiabatic Saturation Lines

Fig. 2—Log-plot psychrometric chart for acetone and air

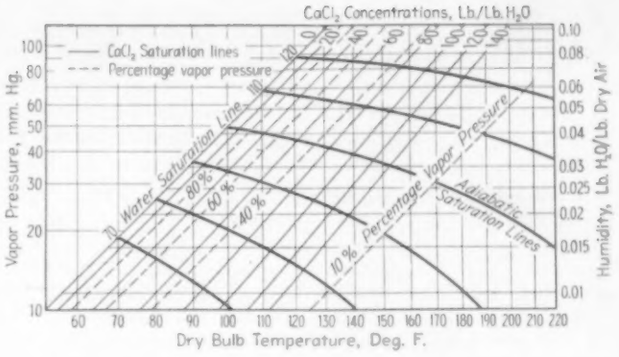


Fig. 3—Chart for aqueous $CaCl_2$ solutions related to air

tion; and these lines are steeper than the water saturation curve.

The most concentrated solution to be considered, 140 parts by weight of $CaCl_2$ per 100 parts water, has a slope of 1.1674, meaning that the heat of disengaging water from this solution is 16.74 per cent higher than for evaporating pure water.

It will be noted from Fig. 3 that the saturation lines for the solutions of several different concentrations fall in among the percentage vapor pressure lines for water itself; but since they are not parallel to the water line, they do not coincide with these relative humidity lines.

The adiabatic cooling lines or lines of constant enthalpy are drawn in Fig. 3 in relation to the saturation line for water itself. If the lines of various saturations were parallel to the water line, i.e., had the same latent heat as water, as in the above mentioned case of sodium chloride, for example, the same adiabatic cooling lines would serve for all concentrations. Strictly, the adiabatic cooling lines should be drawn separately for any given solution of $CaCl_2$ which is to be used in operation. Within minor inaccuracies, the adiabatic cooling lines for water may be used for the solutions of lower concentration.

An interesting application of this use of the adiabatic cooling lines is in the usual case of dehydration by means of such salt solutions wherein the point representing the relative partial pressure of water will fall between the saturation curve for water and the relative partial pressure line for the solution. The path of the operation of dehydrating the air may be indicated on the chart by the adiabatic cooling line on which is the point representing the initial condition of the air; and the intersection of this adiabatic line with the line of the solution in question is the terminus of the air at a higher temperature and lower humidity. This, of course, does not take into account any temperature difference of the solution, but neither does the ordinary case of humidifying take into account the temperature of the water. In both cases this may be corrected for. In this dehydration operation there should be included in such correction, if necessary, the different specific heat of the liquid as compared to water.

The same relation of psychrometric or wet bulb lines in reference to the solutions may be followed in this case by using adiabatic cooling lines, just as for water in the usual case, since both depend on the vapor-gas characteristics, which are the same.

It is apparent that as dehydration continues the concentration of the salt solution will change.

Solvent Recovery

In the case of solvent recovery by scrubbing, or in other cases where two or more volatile components are to be considered in relation to their vapors in a stream of air or other non-condensable gas, this plot offers a satisfactory method of study and representation. One example may be taken as that of the washing of the vapors of acetone or other water-soluble solvent from an air stream by means of a spray of water. The complications which arise in the graphical presentation and solution of this problem are considerable. One simplifiaction may sometimes be made in case the air is recycled. Here there is always some water vapor carried through the dryer where the acetone vapor is absorbed and through the spray chamber where it is removed and thence back to the dryer. The amount of water vapor per pound of air, may be assumed to be uniform throughout this process; and thus a chart may be drawn using the air with whatever water vapor may be present as the permanent carrier gas. A further simplification is the assumption that the liquid concentration is constant, for example, at the discharge of the scrubbing system where the liquid is going to the recovery still.

The same thory as developed above for the partial pressure of water from salt solutions may now apply and the lines of relative partial vapor pressure of acetone from solutions of water may be used. The water may be regarded as non-volatile since the air is charged with water vapor by reuse; and the washing out of the acetone may be studied as a dehumidification operation along the adiabatic cooling lines. Similarly, stripping of acetone by blowing moist air through an acetone-water solution may be considered as a humidification operation.

If the above suggested assumptions may not be made, a very complicated problem is presented since in the general case acetone may be going into the air while water is coming out and the presentation is very difficult. Furthermore, it must be noted that the acetone-water ratio in the vapor phase will not be the same as the acetone-water ratio in the liquid in equilibrium therewith; but it may be approximated by the usual vapor composition relations. The latent heat used in calculating an adiabatic cooling line would thus be that of the equilibrium mixture in the vapors rather than that of the liquid solution itself. The present chart, however, offers a basis for even such studies.

The 100 per cent vapor pressure line for pure acetone (corresponding to the vapor pressure of acetone) may also be plotted on a chart for water-air such as Fig. 1. It will be a nearly straight line of a different slope to the left of the water saturation line. Since acetone does not form a constant boiling mixture with water, the vapor pressure lines (total vapor pressure) of the solutions of different amounts of acetone and water will fall between the acetone line and the water line. (The partial pressure lines for acetone will be straight, but will not all be above the saturation line for water). Any final concentration of acetone in water may be either selected or assumed as the operating conditions of the spray chamber in question and will represent the concentration of the liquid leaving. This line will, therefore, be the 100 per cent line for whatever conditions may be encountered in the spray chamber. The adiabatic cooling lines may be drawn; and it will be necessary to use in their calculation a value for the latent heat of a mixture having a composition in equilibrium in the vapor state with that of the composition of the liquid rather than the latent heat of the liquid itself.

Condensation by Refrigeration

By *JAMES W. HUNTER*, Mechanical Engineering Dept., Pratt Institute, Brooklyn, N. Y.

Reducing the vapor content of a gas, such as lowering the humidity of air, is most often accomplished by cooling the gas with refrigeration. The principles and methods of using refrigeration for this purpose, and the types of refrigeration cycles, are briefly reviewed here.

SEPARATION of condensable vapors from non-condensable gases is almost always accomplished by causing the condensation of the vapor. Condensation is brought about either by cooling the gas below the saturation temperature of its vapor; or by bringing the gas into contact either with a liquid which has a lower vapor pressure of the vapor than exists in the gas, or with a solid having a high capillary attraction. In these last cases, represented by absorption and adsorption, the vapor in the gas migrates to the material and condenses until the vapor pressure in the material attains equilibrium with the partial pressure of vapor which is present in the gas.

Use of refrigeration for vapor concentration lowering can best be illustrated by the processes used for removing moisture from air. These methods include passing the air across cooled surfaces; or passing the air through an air washer in contact with cooled water or brine. The cooled surfaces are generally coils through which either a refrigerant, brine or cooled water is circulated.

In order to understand just what is happening in each of these processes we shall refer to the skeleton charts, Figs. 1 and 2. In Fig. 1, air with w_1 grains or pounds of moisture (7,000 grains = 1 lb.) at a dry bulb temperature t_1 is passed across a coil or finned tube surface whose average surface temperature is t_s (below the dewpoint corresponding to t_1). For a given velocity of air, velocity of fluid in the tubes and arrangement of the tubes there is a definite value of t_2, the exit temperature of the air. At t_2 the moisture content is w_2 and we have removed by this process w_1-w_2 pounds or grains of moisture. The moisture removal expressed in heat units is a definite proportion of the sensible heat removal. For air and water vapor this equation, according to W. L. Knaus (*Refrig. Eng.*, Jan. and Feb. 1935), is $LC/SC = 0.62\ (w_1-w_2)/(t_1-t_s)$, where LC is the latent heat removal capacity of the coil and SC is its sensible heat removal capacity.

If we are to use an air washer the process will be represented somewhat differently on the psychrometric chart. The short-circuiting characteristics of a coil prevent its producing complete saturation of the air, and a leaving relative humidity of about 90 per cent is usually to be expected. An air washer, however, can come much closer to saturation of the air, producing a leaving relative humidity of 95-97 per cent on the average. Therefore, such a process is generally represented, not as a straight line between the initial and final conditions, but as a sensible cooling line to the saturation curve, followed by a reduction of moisture along the saturation curve. Fig. 2 illustrates this process. Air with an initial temperature t_1 and a moisture content w_1 is cooled to point (a) and then to point (2). By reheating the air its final condition can be brought to point t_3, just as in Fig. 1. In either case, of course, reheating may be desired to produce such a final temperature such as t_3, since cold, nearly saturated air cannot be used in some cases.

The spray washer employs refrigerated or cold water and, as in Fig. 2, removes sensible heat along the line (1)-(a) and sensible and latent heat and heat of the liquid along (a)-(2). Reheating adds sensible heat along (2)-(3). The moisture removal is w_1-w_2. If saturated air is desired, it is withdrawn at point (2).

The temperature produced at point (2) depends, of course, upon the efficiency of the washer. The efficiency increases as the number of spray banks is increased from one up to a maximum of about three. The velocity of air through a washer is about 500 ft. per min. If dust removal is important, scrubber plates which are simply plates over whose surface water is flowing are provided at the entrance end. Eliminator plates at the outlet accomplish removal of mechanically entrained water. Ordinarily about 3.5 gal. of water per min. per ton of refrigeration is required. (A ton of refrigerating capacity means the removal of 200 B.t.u. per min., or 12,000 B.t.u. per hour.) In some types of washers, refrigeration coils are placed directly in the lower part of the spray chamber, and both spray water and air come in contact with the wetted coils. Such a washer is described as being equipped with Baudelot coils. Some engineers have recommended the use of about 35 ft. of 1½-in. direct-expansion piping per ton of refrigeration for such a coil.

The section commencing on this page deals with the principal methods used in separating gas-vapor mixtures. All of these methods depend upon producing condensation of the vapor, either by cooling, by solution or by physical adsorption, each of which methods is covered by one or more articles. Another article discusses factors entering into choice of a dehumidification method, while the last of the section is concerned with humidification processes.—Editor.

Adiabatic cooling of air, which is accomplished by increasing its moisture content with recirculated, uncooled spray water along an adiabatic saturation line of the psychrometric chart, should not be confused with refrigeration cooling. (Adiabatic saturation cooling is covered on p. 316, this issue —Ed.) Refrigeration cooling above the saturation temperature results in no change in moisture content. Refrigeration cooling to temperatures below the initial saturation temperature results in a decrease in moisture. Adiabatic cooling, on the other hand, is cooling at constant total heat, accomplished by increasing the dewpoint temperature of the air.

Refrigeration System

Refrigeration for air conditioning is provided by direct compression systems utilizing reciprocating or centrifugal (and occasionally rotary) compressors; steam jet refrigeration systems; and to a small extent, by absorption refrigeration.

In the direct compression system any one of many refrigerants may be used. The choice depends to a considerable extent on the condenser pressure desired. Thus with carbon dioxide, pressures from 500 to 1,000 lb. per sq. in. are employed, while with some of the organic refrigerants used in centrifugal compressors, pressures throughout the system are sub-atmospheric.

Very briefly a refrigeration cycle consists in condensing the compressed refrigerant with air or water cooling, the condensed liquid being collected in a receiver. The liquid then flows through an expansion valve into an evaporator where it vaporizes, the latent heat for the vaporization coming from the surroundings and from the sensible heat of the refrigerant liquid. The evaporator may be either a coil over which the air, gas, water or brine to be cooled is passed, or in some cases, it is a chamber in which the cooling coil for the water or brine is placed. After vaporization, the refrigerant is delivered back to the compressor to complete the cycle.

The reciprocating type of compressor is used for such refrigerants as carbon dioxide, ammonia, and those having relatively small specific volume under the conditions of operation. The centrifugal compressor is now being widely used for refrigerants of low condensing pressure and high specific volume such as water vapor, methylene chloride and monofluorotrichloromethane (F11). Centrifugal compressors are direct connected to steam turbines or electric motors. Frequently centrifugal condensing equipment is

built as a unit of compressor, condenser and evaporator as in Fig. 3. Here the refrigerant is compressed in the centrifugal and delivered to the condenser, from which the condensed liquid drains to a float valve chamber and then to the evaporator. Here it rises around the tubes containing the brine to be chilled. The refrigerant vapors pass through an eliminator and return to the compressor at a low pressure for recompressing and recycling. Since internal lubrication is not required, fouling of the heat transfer surfaces is avoided. Since units of this type often have sub-atmospheric pressures at all points, in-leaking air and water vapor must be purged continuously.

One refrigeration scheme which has found favor, particularly where exhaust steam is available, is the steam jet type. This unit may be designed for operating at steam pressures as low as 12-15 lb. per sq.in., or as high as 125 lb. per sq.in. The steam jet is used to reduce the pressure in a closed container of water, which results in the evaporation of some of the water and the reduction of the temperature of the remaining portion to a point corresponding to the pressure maintained. At low absolute pressures, the specific volume of steam is great and a compressor of large volumetric capacity must be employed. For example, if a vacuum of 29.75 in. of mercury were maintained, the specific volume of the vapor would be about 2,500 cu.ft. per lb.

Centrifugal compressors have been used to some extent with water vapor refrigeration, but the steam jet compressor or ejector is much more common. Fig. 4 shows a schematic diagram of such a unit. The water to be cooled passes into the evaporator, through sprays. Owing to the vacuum maintained by the jet, approximately 1 per cent of the water is evaporated for each 10 deg. of cooling. The chilled water is delivered to an air washer or cooling coil by a pump. The vapor removed from the evaporator, together with the steam used, is condensed with a primary condenser. Secondary ejectors and condensers are provided to remove air and non-condensable vapors from the primary condenser. The condenser discharge may be used to provide hot water, and the system has a further advantage in that no hazard exists from the refrigerant and hence the equipment may be installed at any point in the plant. Investment is generally less than for an equivalent ammonia system. The determining factor in choosing a jet system is often the availability of cooling water in sufficient quantity at the desired temperature. Lacking moving parts except for the pumps, this system is, of course, quiet in operation.

Absorption refrigeration appears to be of little interest in air conditioning at the present time. This method is used to some extent in ice manufacture, and also in household refrigeration. A relatively small number of installations are used in air conditioning where the heat balance of the plant can be improved through the use of this method. Absorption refrigeration can employ exhaust steam or waste heat, the latter possibility being more favorable for the absorption method than for steam jet refrigeration. In the absorption method, the compressor of the mechanical system is replaced by a "generator" containing a solution of the refrigerant. Heat is supplied, forcing the refrigerant vapor over into the condenser at sufficient pressure to cause its condensation.

Cooling Coils

Coils used for cooling and moisture condensation in air conditioning include pipe coils, manifolds with attached piping, and extended surface tubes. Cooling water allowed to drip on such coils will provide a wetted surface and so give better heat transfer. If the direct expansion system is used, more refrigerant must be provided than in the case where an indirect system, using cold water or brine is used.

Often the choice of means for applying refrigeration hinges on the possible toxic effects of the refrigerant vapor should it escape into the conditioned air. Local code requirements as to the refrigerant and system will often give the answer, which must otherwise be determined in relation to the type of installation contemplated and its intended location in the building to be conditioned.

Fig. 1, Left—Schematic diagram of cooling and dehumidification with a coil
Fig. 2, Right—Schematic diagram of cooling and dehumidification with a cooled spray in a spray washer

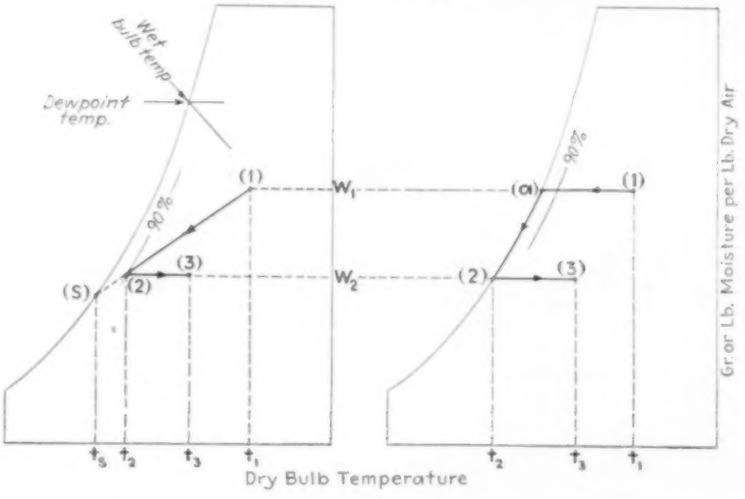


Fig. 4, Below Left—Typical set-up for steam jet refrigeration

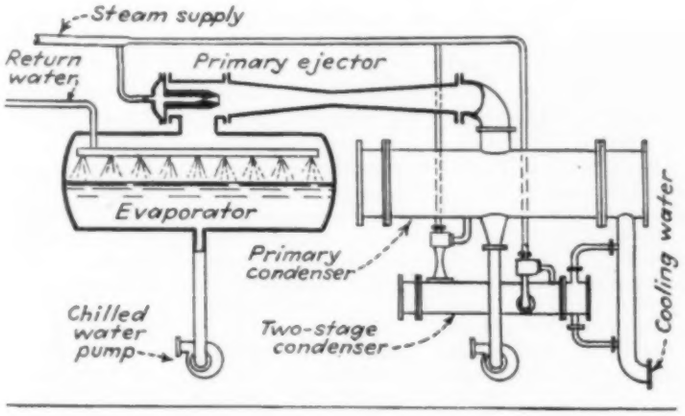
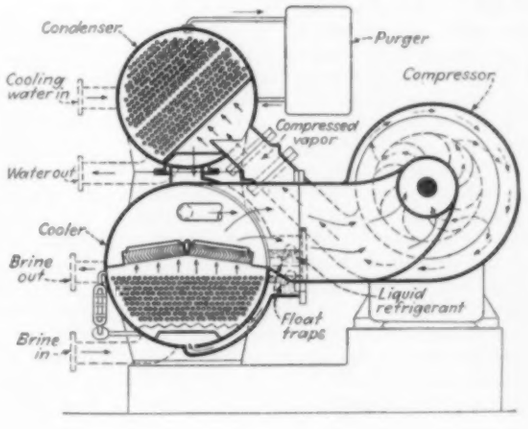


Fig. 3—Diagrammatic cross section of Carrier centrifugal refrigeration machine



Absorbent Solutions

By *F. RUSSELL BICHOWSKY*, consulting engineer, Ann Arbor, Mich. To precede the more detailed discussions of lithium and calcium chloride solutions which follow this article, Dr. Bichowsky has been asked to prepare the following short comparison of materials for absorbing water vapor from gases.

SUITABILITY of an absorbent solution for dehydration of air or gas depends on the following factors: (1) Relative humidity of the air that can be obtained using a saturated solution at the desired temperature. (2) Relative humidity of the air that can be obtained using a solution saturated at the lowest temperature to which the apparatus is exposed. (3) The eutectic temperature of the solution. (4) The heat of dilution of the solution, which is known accurately only for some solutions but which is approximately the same for all saline solutions. (5) The water capacity of the solution, e.g., the amount of water that can be taken up by 1 lb. of solution in the range between 19 and 20 per cent relative humidity. (6) The absorption coefficient which depends on the apparatus but which is substantially the same for all electrolytic solutions. (7) The viscosity which is known accurately in only two cases, but which can probably be taken to be the same for all solutions of equal drying power.

Other factors include: (8) The corrosion due to electrolytic action. This is most marked where dissimilar metals are used in the apparatus which should therefore in all cases be constructed of electrically similar metals. (9) Oxidation corrosion, which is the ordinary form of corrosion due to dissolved air. None of these solutions is much worse than pure water in this respect, at least in the concentrations actually used. (10) Acid corrosion, which is the corrosion due to solution of the metal in the acid. This is severe only with sulphuric acid, and with zinc chloride and calcium salts if these solutions are acid. (11) Chemical stability, a factor which is not troublesome for any of the usual absorbents at room temperature but may be so at the higher temperatures.

Finally, still another group of criteria include: (12) Toxicity to foods. None of these solutions introduce any important health hazards in ordinary use but in cases where there is chance of spray being carried into a foodstuff, precautions should be taken in the use of several of these agents. (13) Commercial availability. Several of the solutions concerned are patented and consideration should be given to this fact in proposed applications. (14) Cost. Absorbent solutions fall into three rather distinct cost groups: those costing less than 10 cents a pound, those whose cost ranges between 10 and 50 cents a pound and those costing more than 50 cents. (15) Odor removal. Very little is known of this factor which is of considerable practical importance, but no one should expect to use these solutions for air conditioning without counting also on use of fresh air.

No one absorbent meets all the listed requirements equally, so the choice of an absorbent for a given use always involves balancing the various factors against each other. To assist in such balancing the accompanying table is provided.

Except for glycerine and similar solutions, absorbent systems have substantially the same thermodynamic efficiency. The reason systems employing glycerine are less efficient is because of the small capacity of the solution to take up water at low relative humidity.

The various absorbents differ in the dryness of the air that may be obtained. For a majority of air conditioning purposes, air of 20 per cent relative humidity is dry enough but there are many cases where much drier air is needed, particularly for chemical purposes, and it is usually advisable to work with drying solutions at the highest temperatures possible to keep cooling water consumption low. For these reasons there has been a tendency to use solutions of as great drying power as possible, considering the greater cost of these solutions. This is particularly true where solutions are to be used adiabatically as in blast furnace work and in adiabatic drying.

There are other cases where higher relative humidities are entirely satisfactory. In these cases calcium chloride *and its mixtures*, is often entirely suitable. When calcium chloride can be used it results in considerable saving in first cost, even in standard apparatus. In cases where standard apparatus is not economically justified, it is often possible to use very simple apparatus, such as a screen-bottom barrel containing lump material, provided with a blower for forcing air through the lumps, and a tank to catch spent calcium chloride solution, which is thrown away.

For bone dry air required in many chemical operations, there are still no better absorptive agents than sulphuric and phosphoric acids.

Comparison of Various Absorbent Solutions, Sulphuric Acid and Glycerine

	Lithium Chloride	Calcium Chloride	Zinc Chloride	Calcium-Lithium Mixture*	Calcium Chloride, Bromide	Sulphuric Acid	Glycerine
Relative humidity at 90 deg. F. of saturated solution, per cent	11	21	5	3	9	0	0
Relative humidity at 60 deg. F. of saturated solution, per cent	14	37	6	7	?	0	0
Eutectic temperature, deg. F	−90	+88	47	low	low	low	low
Heat of dilution B.t.u. per lb	200	same	same	same	same	same	low
Water capacity per per cent relative humidity at 20 per cent relative humidity, per cent	3	2	3	1	1	3	0.2
Absorption coefficient	Approximately the same for electrolytes						?
Viscosity	Approximately the same for solutions of equal drying power						
Electrolytic corrosion	bad	bad	bad	bad	bad	bad	none
Oxidation corrosion (compared with water)	same	same	same	worse	worse	same	less
Acid corrosion	none	none	none	none	none	bad	none
Chemical stability	stable	stable	hydrolyzes	.....	.....	stable	oxidizes
Toxicity (to foods)	none	none	unsafe	doubtful	doubtful	unsafe	none
Availability	patented	free	free	patented	patented	free	free
U. S. patent number	1,992,177			2,143,008	2,033,934		
Cost	high	low	low	high	moderate	low	moderate
Odor removal	fair	fair	fair	?	?	?	?

*Dow Chemical Co. patent on mixtures of lithium and calcium, chloride and bromide ions.

Lithium Chloride

By *EDITORIAL STAFF*. At present the hygroscopic salt most used for absorbing moisture from air is lithium chloride. Solutions of this material have a low vapor pressure of water, have a relatively low viscosity, and, in the concentrations ordinarily employed, do not crystallize out at temperatures likely to be met in use.

OWING to the low relative humidities obtainable with lithium chloride in the form of concentrated solutions, interest in the use of this material in the conditioning of gases and air has been increasing rapidly in recent years. Dehydrating solutions of the concentrations ordinarily employed are capable of absorbing moisture to a relatively low dewpoint even at the fairly high temperatures obtainable with cooling water from ordinary sources. City water, cooling tower water and evaporative condensers may be used. In most cases available water will be sufficiently cool to provide air of the desired dry bulb temperature and moisture reduction without the use of auxiliary refrigeration.

An important advantage of lithium chloride is that, even with a high concentration, solutions will not start to

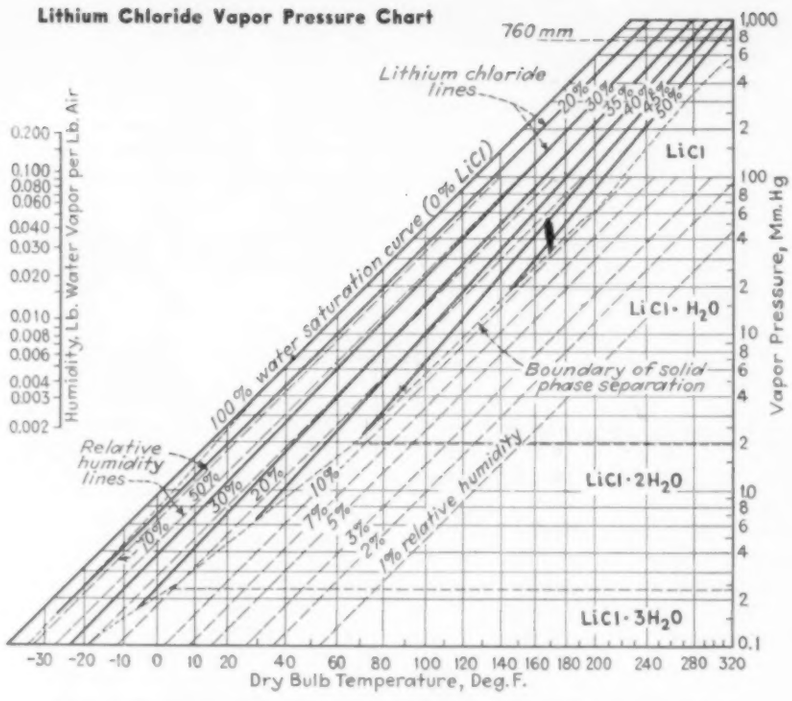


Fig. 2—Vapor pressures of lithium chloride solutions on a water-air chart

Plotted by *Chem. & Met.* from data of the A. S. H. V. E., using the Othmer method (see p. 296), showing boiling points of solutions at pressures up to atmospheric, regions in which LiCl starts to separate in various hydrated forms, vapor pressures of LiCl solutions at various temperatures, and relative humidity lines for air-water vapor mixtures

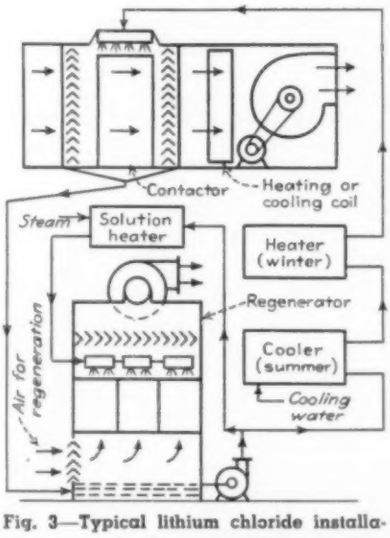


Fig. 3—Typical lithium chloride installation for maintaining constant dewpoint

separate crystals at the temperatures ordinarily encountered in use. The 44.5 per cent solution ordinarily used begins to crystallize at about 67 deg. F. but even a serious degree of cooling, such as might occur in winter with the system shut down, will generally not be enough to solidify the solution in the pipes. Rather, a slush which is still pumpable will ordinarily be formed. A 44.5 per cent solution cooled to 0 deg. F. will crystallize out only about 15 per cent of the LiCl (as $LiCl.2H_2O$) whereas a 40 per cent solution will lose only 5 per cent in cooling to this temperature. A 35 per cent solution does not commence to crystallize above a temperature of about – 16 deg. F.

Lithium chloride is non-poisonous, non-flammable and non-volatile. Owing to the last property the only possibility of losing LiCl from the system is through mechanical entrainment and this loss can be made minute through the use of proper entrainment separators. Lithium chloride solutions of course have a vapor pressure of water at all temperatures, which property makes it possible to regenerate them, but the salt itself will not vaporize. Organic chemicals used for dehydration, on the other hand, do have a definite vapor pressure of their own which, although it may be too small at the temperature of use to cause appreciable loss of the material, may be large enough at the temperature of regeneration to require special precautions to avoid loss.

Lithium chloride solutions of useful concentrations have the lowest vapor pressure of water at normal temperatures of use of any single salt solution, so far as is known (although certain combinations of salts can produce even lower vapor pressures). Hygroscopic salt solutions can be used for the dehydrating of air because, with their lower vapor pressure of water, the moisture in the air will pass to the solution and condense therein until the partial pressure of moisture in the air attains as a limit the vapor pressure of water from the solution. To examine this phenomenon, consider a closed vessel in which is a solution of lithium

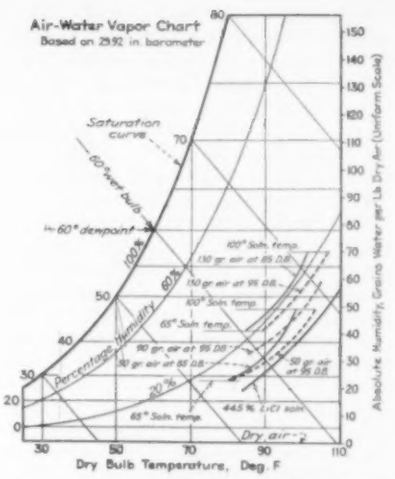


Fig. 1—Final air-condition curves given by a typical contactor for air and LiCl

chloride in contact with air. Assuming adiabatic conditions (i.e., that heat neither enters nor leaves the vessel) the solution will absorb moisture from the air until both solution and air have the same vapor pressure of water. However, as water condenses in the solution, its heat of condensation (equal to the latent heat plus the heat of dilution) is given up to the solution, raising its temperature somewhat. Thus at equilibrium the solution is both more dilute than initially, and at a higher temperature, both of which effects raise its vapor pressure of water above the initial vapor pressure. It is evident therefore that to produce a predetermined vapor pressure at equilibrium (after absorption of moisture from the air) the initial temperature must be lower and the concentration of the solution must be higher than those corresponding to the final vapor pressure.

This analysis, based on static conditions, also applies in a general way to the continuous flow conditions actually employed, except that dynamic operation approaches but does not reach the conditions of equilibrium, approaching more closely as the contact area between air and solution, and the contact time, increase. Actual equipment ratings therefore depend upon design factors, the ratings necessarily being based upon the empirical results of actual tests. Experience indicates that in a properly designed contactor, end conditions of the air can be predicted with a considerable degree of accuracy from an examination of a vapor pressure curve for the strength of solution employed, plotted on a psychrometric chart. Solution temperature, air dry bulb temperature and air moisture content all affect the final air condition. For air at constant initial moisture content and dry bulb temperature, a plot of the final air conditions for various solution temperatures will result in a line on the psychrometric chart which is substantially parallel to the vapor pressure line for

the solution, but to the left of it. Higher solution temperatures result in higher final dry bulb temperatures, but substantially the same final relative humidities for the same initial air conditions. The higher the initial moisture content, however, the higher the final moisture content and relative humidity for the same solution temperature and initial dry bulb. Fig. 1 is a plot showing these relations approximately for one type of contactor when supplied with solution at temperatures from 100 deg. down to 65 deg., for initial air of 130, 90 and 50 grains per pound moisture, at dry bulbs of 95 and 85 deg.

Fig. 2 is a plot of the vapor pressures of lithium chloride solutions of 20, 30, 35, 40, 45 and 50 per cent concentration, plotted according to the new Othmer method shown on p. 296 of this issue, against temperatures from −40 to 320 deg. F. Thus the plot covers the range from the lowest temperatures that might be used, to the temperatures required for the regeneration of the solution. For greater accuracy of reading a similar type of chart can easily be plotted by Othmer's method, either larger or for a lesser range. Note that the chart shows the boundary line at which LiCl or its hydrates begin to crystallize out as the temperature is lowered, and also shows the region of ice formation for the more dilute solutions at lower temperatures.

Just as lithium chloride solutions can be used for dehydration, at higher temperatures they can be used for humidification provided that the solution vapor pressure at the existing temperature is greater than the partial pressure of water in the air to be humidified. This property is of interest in that the same solution can be used in winter for humidification as is used in summer for dehydration. The temperature is raised so that the air is both heated and humidified.

From what has been said about the use of solutions for controlling the moisture content of air, it will be clear that their ability to reduce the air humidity does not depend in any way on changing the temperature of the air, as does refrigeration. In fact, it is theoretically possible to dehydrate air at constant temperature by removing the heat released by the condensing moisture as rapidly as formed. Actually this is not done and the heat of condensation raises the temperature of both the solution and the air under most circumstances. The net effect after cooling the dehydrated air is, of course, the same. Ability to control the dewpoint of air independent of the dry bulb is frequently an advantage.

Air and lithium chloride solutions can be brought into contact in various types of equipment providing for a considerable area of contact. In the type of equipment furnished by the Surface Combustion Corp., the contactor is a chamber provided with efficient spray eliminators, containing a group of parallel vertical plates which are sprayed with 44.5 per cent solution, between which the air flows. From the contactor the solution flows to a sump from which it is recirculated by a pump to the contactor, passing first through a cooler where the heat of condensation is removed. It will be noted from Fig. 3 that a part of the circulated solution is diverted to the regenerator for reconcentration. This part of the solution is first passed through a heater where it is heated with steam to some such temperature as 210 deg. F. The hot solution is then sprayed over plates similar to the contactor plates between which regenerating air is blown. The air passing through the regenerator cools the hot solution to a considerable extent and picks up a high concentration of moisture, sufficient to bring the bulk of the solution to its original concentration. This air is, of course, discharged outside the conditioned space.

For assistance in the preparation of the manuscript the editors are indebted to E. A. Windham, air conditioning engineer of the Surface Combustion Corp., Toledo.

Calcium Chloride

By *EDITORIAL STAFF*. Cheapest chemical available for dehydrating air and other gases, calcium chloride has long attracted attention in this field. Recent improvements in its production and method of application have led to a more successful use of the salt.

OWING TO ITS AVAILABILITY as a cheap byproduct of the ammonia-soda process of soda ash manufacture, calcium chloride (in both solid and solution forms) has long been of interest as a dehydrating agent for air and gases.

C. R. Downs, in association with the Research Corp., has recently applied calcium chloride most effectively in this field. He found that by pouring molten calcium chloride of about 72 per cent $CaCl_2$ into a suitable type of traveling mold, he could produce uniform non-porous lumps. While the chloride is in the molten state, wetted activated carbon can be dispersed in it to impart the additional property of odor adsorption. This material is the patented absorbent, Caloride.

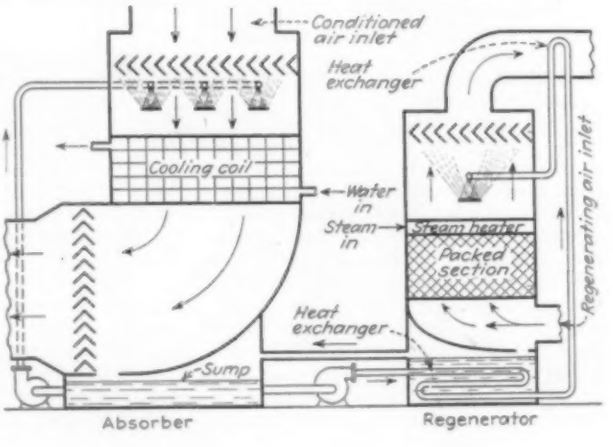
Equipment has been developed and patented by Downs for applying this material to the dehydration of air in both residential and industrial air conditioning. The residential unit employs both solution and solid material, to which the moist air is exposed in series. However, our main interest here is in the industrial type installation, which uses calcium chloride solution, reconcentrated as it becomes diluted in use. With the regenerative cycle (see accompanying illustration), dehydration is performed in an air-liquid contactor, where the air, saturated with solution, passes through cooling coils, is separated by spray eliminators and emerges at a predetermined lower humidity. About one-sixth of the solution is continuously withdrawn from the sump to the concentrator, where it is regenerated with low-pressure steam and air.

Vapor pressure relations for calcium chloride solutions of various concentrations are given by Othmer (see page 298). The curves represent equilibrium conditions rather than the dynamic conditions which prevail in a continuously operated unit. However, it is claimed that by proper design it is possible to approach within about 2 per cent humidity of equilibrium conditions.

In general calcium chloride solutions are best suited to higher temperatures and higher humidities. However, for installations requiring air of 40 per cent humidity or more, calcium chloride appears to be equally as suitable as lithium chloride.

One material advantage claimed by Downs for air dehydration with a liquid absorbent in contact with a cooling coil (which of course removes the heat of condensation and dilution as rapidly as formed) is the remarkable constancy of air outlet conditions that can be attained with widely varying inlet moisture concentration and dry bulb temperature.

Calorider absorber and regenerator for use with calcium chloride and other absorptive liquids for the dehydration of air



Activated Carbon Adsorption

By *CHARLES L. MANTELL*, consulting chemical engineer, New York. **In addition to writing on the properties and uses of activated carbon, Dr. Mantell has been asked to introduce the subject of adsorption in general, giving comparative information on the principal adsorbents, activated carbon, silica gel and activated alumina.**

A VARIETY of solids of an essentially porous nature, each with a definite affinity and selectivity for the adsorption of certain vapors, has been developed for industrial use in the recovery of solvents, dehydration of gases, fractionation of mixed gases, deodorization in connection with manufacturing processes and air conditioning, as well as other applications. The commercial materials include a variety of clays, chars, activated carbons, gels, alumina, and silicates. Of this group, commercial development and engineering adaptation as far as adsorption from gases is concerned has been effectively limited to three materials, activated carbon, activated alumina and silica gel. Information herein on activated carbon applies mainly to the "Columbia" brand which is marketed by Carbide and Carbon Chemicals Corp. This carbon is a typical example. Activated alumina is the trade-marked product of the Aluminum Ore Co. while silica gel is made by the Davison Chemical Corp.

These products are more or less granular in form, although in recent years extruded and preformed blocks

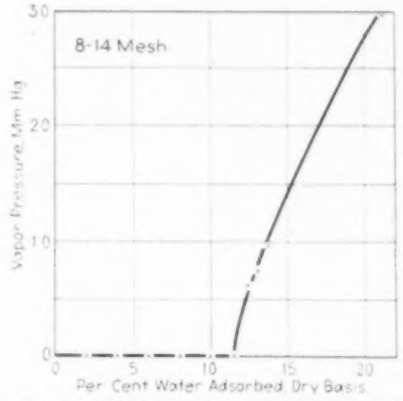


Fig. 1—Variation of vapor pressure of activated alumina, with water content, during dynamic adsorption from air at 86 deg. F. and 90 per cent R.H.

or rods of activated carbon, first used in European practice, have found favor in the United States.

The adsorbent is the heart of the adsorption system, which must be designed to a greater or lesser extent around the physical and chemical properties of the adsorbent. It may be said of each of the commercial materials that they show from the engineering viewpoint the highest effective adsorptive capacity under conditions of use, they are readily activated, and easy release of the adsorbate is accomplished. From the viewpoint of power consumption when gases are moved through a system, all of the commercial adsorbents show low resistance to air or gas passage, with an optimum shape and size of particles for the particular apparatus, a long life in service due to high resistance to breakage and deterioration during use, which in turn is backed by uniform quality of material assured by close manufacturing control. The properties and applications of the solid adsorbents are given in Table I, where the adsorbents are those of the manufacturing companies mentioned above.

The more or less granular solid adsorbents are supported in beds or columns of suitable thickness through which the gas from which the vapor is to be adsorbed may be passed. Commercially, activated alumina and silica gel, being highly selective to water adsorption, are employed for dehydration of air and gases as well as dehumidification and air conditioning. Activated carbon finds its major application in solvent recovery, odor and taste removal, and related applications. It is, therefore, evident that activated carbon does not compete with activated alumina or silica gel. The solid adsorbents are ordinarily chemically

Table I—Properties and Applications of Solid Adsorbents

	Activated Carbon [1]	Activated Alumina [2]	Silica Gel [3]
Apparent density	0.7–0.9	1.6	0.7
Specific gravity	1.75–2.1	3.25–3.35	2.1–2.3
Avg. weight, lb. per cu. ft.	28–34	50	38–40
Avg. porosity, per cent	50–55	51	50–65
Thermal conductivity, B.t.u. per sq. ft., hr. deg. F. and in.		1.45 (200°F.) 1.0 (100°F.)	1
Specific heat, B.t.u. per lb. and deg. F.	0.2	0.24	0.22
Reactivation temp. range, deg. F.	Avg. 220–240 Special up to 575	350–600	300–350
Activation method			
Live steam, direct contact	X		
Preheated gas or air		X	X
Waste gas or flue gas from gas or oil		X	X
Embedded electrical heaters	X	X	X
Embedded steam coils	X	X	X
Specific surface, sq. cm. per g			6×10^6
Avg. pore diam., cm			4×10^{-7}
Hardness, resistance to breakage (U.S.C.W.S.)	80–98		
Adsorptive capacity, CCl_4 from air at 25 deg. C., sat. at 0 deg. C., weight per cent	50–90		15–35
Retentive capacity, CCl_4 retained at 25 deg. C. after 6 hr. in dry air stream, weight per cent	25–40		2
Service life (Accel. chlorpicrin test, U.S.C.W.S.), minutes	40–65		
Heat of wetting with benzene, cal. per g	20–26		
Commercial flow rates for complete drying of gases, cu. ft. per hr. and lb.		25–50	25–75
Commercial gas velocities, ft. per min.	20–120	25–100	25–100
Effective bed temp., deg. F.	40–120	32–80	40–90
Weight adsorption of water at break point, per cent, dry basis		12–14	10–20
Weight of water at saturation, per cent, dry basis		20–25	40

	Activated Carbon [1]	Activated Alumina [2]	Silica Gel [3]
Applications			
Drying air		X	X
Drying non-reactive gases		X	X
Drying reactive gases			X
Gas and air conditioning		X	X
Gas concentrating (SO_2)			X
Petroleum vapor desulphurizing			X
Gaseous fuel drying		X	X
Oil vapor adsorption (filtration)	X	X	X
Solvent recovery	X		
Gasoline from natural gas	X		
Benzene from mf'd. gas	X		
Odor, taste removal from CO_2	X		
Fractionation of gases (He from natural gas)	X		
Stench abatement	X		
Odor removal, air conditioning	X		
H_2S adsorption	X	X	X
Alcohol from fermenter gases	X		
Commercial sizes, screen mesh	4–8, 6–8 4–14, 6–14, 8–14 10–24, 14–35 through 200	2–1 in., 1–2, 2–4 4–8, 8–14, 14–20 20–40, 40–80 through 80	Various, also through 200
Pressure drop for 8–14 mesh bed 5 in. thick, in. water			
At 75 f.p.m. lin. vel.		2.4	
At 50 f.p.m. lin. vel.		1.1	
At 25 f.p.m. lin. vel.		0.5	
Important U. S. Patents	1,497,543 1,497,544 1,815,554	1,868,869 2,015,593 1,985,204 1,985,205	
Common adsorbent arrangement			
Vertical columns	X	X	X
Trays			X
Horizontal adsorbers	X		
Screens	X	X	X

[1] Typical analysis: H_2O, 0.5–2.5; ash, 0.5–4.0 per cent; balance C. [2] Typical analysis: Al_2O_3, 92; Na_2O <7; SiO_2 <0.1; Fe_2O_3 <0.1; TiO_2 <0.01 per cent. [3] 99.5 + per cent SiO_2.

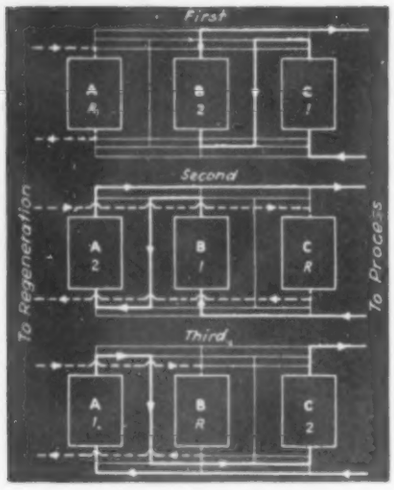


Fig. 4 — Diagram of three-adsorber hookup, showing steps in complete cycle

stable, inert in character, and non-corrosive, although design precautions must often be taken to protect against galvanic and electrolytic corrosion.

Adsorptive efficiency is often determined in terms of vapor pressure obtained by dynamic methods of measurement. It is apparent that the adsorbate is taken up initially at the gas entrance end of the bed of solid adsorbent and that the adsorbent in this section reaches its saturation point before adsorbate reaches the gas exit end of the bed. As flow continues, more of the adsorbent bed becomes saturated. Eventually, in the vicinity of the exit end, the capacity for adsorption is no longer effective at substantially 100 per cent efficiency. A variable degree of saturation exists between the entrance and exit ends. Vapor pressures may be expressed on the basis of the average percentage of adsorbate throughout the bed and the vapor pressure of the adsorbate in the exit gas. Fig. 1 is a curve for water adsorption by activated alumina.

As adsorbate is taken up by the adsorbent, heat is liberated. This may be removed by various cooling methods so that the adsorbent reaches a normal equilibrium point or "break." Adsorption continues, however, but at decreasing efficiency until saturation is reached. If the heat of adsorption be not removed, a hot zone forms at the area of maximum adsorption. This hot zone follows layer by layer the course of adsorption from the entrance to the exit end of the apparatus. The quantity of heat liberated is dependent upon the concentration of the adsorbate, the heat content of the gas, the rate of flow, frictional effects, and other factors. The heat liberated during adsorption from a practical viewpoint may be considered as about equal to the thermal requirements necessary to vaporize an equal amount of adsorbate during activation.

For the same adsorbate, the total weight taken up at 100 per cent emciency in a given apparatus is nearly independent of the initial concentration of adsorbate in the gas. In the case of activated carbon, however, the specific capacity was found by Lamb and Coolidge (*J. Am. Chem. Soc.*, *42*, 1920, p. 146) for a number of gases and vapors to be very nearly proportional to the inverse ratio of their molecular volumes. Generalizations are difficult and misleading, as adsorption is quite specific, being a function of the nature of the gas, temperature, pressure, the exact characteristics of the adsorbent, its activity, origin, mode of preparation, previous history, as well as the operating conditions in the particular plant and the stability or lack of stability of such operating conditions.

In the case of activated carbon for gas masks, the "service life against chlorpicrin" is determined on a volume basis and is a measure of the ability of the carbon to protect against substantially all organic vapors which are not catalytically decomposed. The high density of the carbons enables them to give maximum protection per unit of volume. The "heat of wetting" is believed by military authorities to measure the specific adsorptive power of the carbon and therefore to measure the ability of the carbon to adsorb efficiently and retain organic vapors even when these vapors are present in extremely low concentration and where water vapor is present. The "hardness" of the carbons is a measure of their resistance to breakage or dusting in transportation and use.

Table II—Weight Adsorption of Vapors By Various Activated Carbons

	Adsorption, Wgt. Per Cent	Retentivity, Wgt. Per Cent
Benzene	45–55	5.9*
Carbon tetrachloride	80–110	27–30*
Methyl alcohol	50	1.2 (1 hr. at 150°C)
Ethyl alcohol	50	1.05 (ditto)
Isopropyl alcohol	50	1.15 (ditto)
Ethyl acetate	57.5	4.87 (ditto)
Acetone	51	3.0 (ditto)
Acetic acid	70	2.5 (ditto)

* 1 hr. in sat. steam

Activated carbons are used in relatively thick beds through which the vapor-laden air is passed. The larger particle sizes are preferred in order to keep the resistance to a minimum. The adsorptive capacity data given in the tabulation measure the ability of the carbons to adsorb relatively concentrated vapors, whereas the retentive capacity data measure the specific adsorptive power or ability of the carbons to adsorb and retain at normal temperatures vapors present in low concentration and in the presence of water vapor. Both characteristics must be considered in determining the effective adsorptive capacity of carbons under specific recovery conditions. The adsorbed vapors which are retained by the carbon at normal temperatures are readily released when low-pressure steam is introduced, approximately 3 lb. of steam being usually required to remove 1 lb. of adsorbed solvent. Relatively high "apparent density" is im-

Fig. 2—Pressure drop through activated carbon for various meshes, bed densities and flow velocities

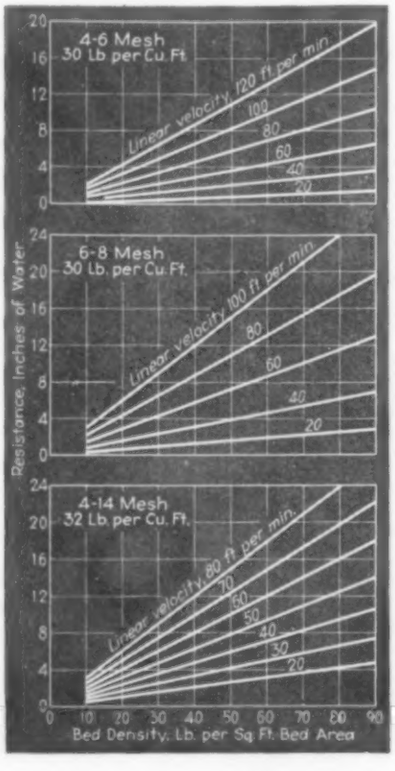
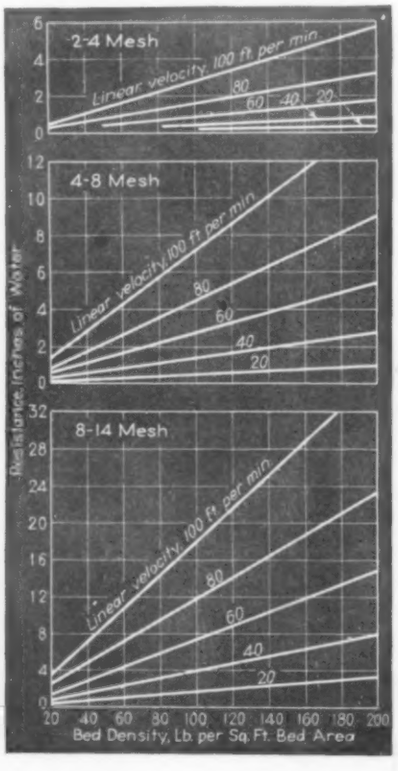


Fig. 3—Pressure drop through activated alumina for various meshes, bed densities and flow velocities



portant because it affects the size of carbon containers and the water absorbing ability of the carbon. The hardness is important because it means greater resistance to breakage during use, and consequent long life.

In commercial plants employing adsorption processes with solid adsorbents, the depth of bed required may vary from a few inches to several feet which, of course, affects the power consumption of the system. The charts of Fig. 2 give the pressure drop at different linear velocities and different bed densities in pounds per square foot of bed area for activated carbons of different meshes. Bed thicknesses may be calculated by dividing the bed densities which are in pounds per square foot by the weight per cubic foot of the adsorbent. Fig. 3 gives similar data for activated alumina.

The effect of the adsorbent on the adsorbate is to accomplish condensation at a temperature above that of saturation. The latent heat of the solvent vapor is given up to the adsorbent and to the unadsorbed gas or air. It may be necessary to cool the gas. Both the capacity and efficiency of adsorption fall off with rising temperature of the bed. Carbon does not selectively adsorb water vapor, so that little latent heat is released through such action. With a moist gas, less heating of both the exit gas and adsorbent bed occurs. When steam is used for regeneration, the moisture remaining in the adsorbent is evaporated owing to its selective displacement by solvent vapor when adsorption is resumed. The cooling effect often makes a precooling period unnecessary.

Recovery is, of course, not completed with adsorption. To release the adsorbate, the adsorbent must be regenerated by the methods given in Table I. Volatized adsorbate is condensed in a surface or other type of condenser and the gas returned to the adsorbers for the stripping of any uncondensed adsorbate. The regenerated adsorber is cooled, if necessary, and returned to cycle. In some instances it is practicable to accomplish regeneration at lower temperatures by application of a vacuum. The volatilized solvent can then be condensed in vacuo.

Three types of arrangement of adsorbent units are in use. Two units generally suffice for continuous operation. Commonly a single bed or series of beds of adsorbent is capable of trapping all of the adsorbate. One unit is operated while the other is being regenerated. In discontinuous operations where there is a shut-down period of sufficient duration to accomplish regeneration, a single unit may be sufficient provided that its capacity is adequate to recover all adsorbate. For continuous operation where a second-stage adsorber is needed to remove adsorbate completely, the three-step cycle is used. This consists of a group of three interconnected adsorbers, two of which are operated on the recovery line in series, while the third is being regenerated.

Fig. 4 suggests diagrammatically the connections used in such a setup, showing how the connections are altered for the three steps of the cycle. In any one step the first adsorber in the line (marked 1) is the partially charged unit which was second in the line in the preceding step, while the second adsorber (marked 2) is the unit which was being regenerated in the preceding step. Meanwhile the third adsorber (marked *R*) is undergoing regeneration (and cooling, if necessary). By this method each unit is rotated in turn through the three steps of regeneration, second stage and first stage adsorption. Since the exit gas from the final adsorber should be practically free of adsorbate, it can be permitted to go to waste. The use of two adsorption stages permits utilizing the ultimate adsorption capacity of each unit, since as the first unit on the line approaches capacity and rises in temperature, any adsorbate escaping will be caught by the second stage adsorber.

Silica Gel Adsorption

By *F. C. DEHLER*, chemical engineer of Davison Chemical Corp., Baltimore, Md. **Owing to its tremendous surface area and exceedingly porous structure, silica gel is a powerful adsorbent for water and other vapors. Especially where low humidities are required, this material is being used to an increasing extent.**

DISCOVERED during the World War by Walter A. Patrick of Johns Hopkins University, silica gel has since found many uses that were not contemplated for this material when it was developed for the Chemical Warfare Service for use in gas masks. Further progress with the material made since the War by the Davison Chemical Corp. has resulted in a product which has been used in the drying of liquids, as a catalyst carrier, in cosmetic and toilet preparations, in the refining of oils, but principally in the drying of gases and air. For this last purpose 6-16 mesh material is usually employed, but for other applications other ranges of mesh size down to impalpable powder are produced. Silica gel is a dehydrated colloidal gel produced under controlled conditions from sulphuric acid and sodium silicate solution. It is an extremely hard and inert material which does not dust in service and because it is chemically silicon dioxide, is unaffected by most chemicals which may come in contact with it.

The adsorptive action of silica gel for vapors is a purely physical effect, the particles suffering no change in size or shape when they become saturated. And even when completely saturated the particles appear perfectly dry. The adsorptive property of the gel arises from its tremendous porosity. The dimensions of the pores are less than a wave length of light and hence sub-microscopic. Two conceptions of the internal structure have been advanced to account for the action. According to the first, silica gel is described as a body of sub-microscopic spherical silica particles piled together in a homogeneous mass similar to a pile of lead shot. The other concept suggests that the gel can be considered to be a mass of strands of silica intertwined indiscriminately and uniformly in all directions after the fashion of threads in a ball of raw cotton. Since the pores or capillaries are formed by the juxtaposition of silica particles, they are not of the same diameter throughout their length and are probably shaped like a wedge.

An idea of the area of the pore surface of silica gel may be obtained from the way it acts in the adsorption of vapors. It is known that every solid is capable of adsorbing gas or vapor on its surface to some degree, and that the weight adsorbed depends upon the nature and extent of the surface. Normal commercial silica gel will adsorb approximately 50 per cent of its weight of water from saturated air and from this it has been estimated that 1 cu.in. contains pores having a surface of about 50,000 sq.ft. This enormous internal surface and infinite number of small diameter capillaries attracts vapors, condenses them, and holds them as condensed liquid in the pores or capillaries.

The weight of any compound adsorbed on silica gel depends upon its partial pressure in the original gas mixture, the temperature of the silica gel and of the gas mixture, the compressability and surface tension of the condensed liquid, its ability to wet the pore surface, and the volume and shape of the pores. In practice, at temperatures normally experienced, silica gel has been found to adsorb large quantities of liquids having boiling points over 50 deg. F. and to release them readily when the gel is heated to about 300 deg. F. Included in this classification are water, ethyl ether, acetone, alcohols, benzene, gasoline, acetates, etc. Silica gel also has quite an affinity for adsorbing more volatile compounds such as sulphur dioxide and hydrogen sulphide.

In industrial applications, silica gel will adsorb vapor from a gas mixture

until the pores of the gel are filled to a point where the internal vapor pressure of the adsorbed liquid in the pores at a given temperature approaches as a limit the partial pressure of the vapor in the surrounding atmosphere at the same temperature. Fig. 1 shows the concentration of water adsorbed in a particular silica gel at various temperatures and vapor pressures. Each of the curves is a constant vapor pressure curve for the silica gel, plotted for the combinations of gel temperature and water content which will yield that vapor pressure.

The amount of a condensable vapor which will be adsorbed in silica gel at any gel temperature increases as the partial pressure of the vapor in the gas approaches the partial pressure of vapor which would exist if the gas were saturated at the gel temperature. This fact will be made clear from an examination of Fig. 1 along, say, the 80 deg. F. line. Silica gel at 80 deg. F. and containing 40 lb. of water per 100 lb. of gel has a vapor pressure of approximately 1 in. Hg, which is the partial pressure of water vapor in air saturated at 80 deg. F. That is, gel at 80 deg. F. in contact with air saturated at this temperature will adsorb up to 40 lb. of water per 100 lb. of gel, as a limit.

Note, however, the lower points along the 80 deg. line. Air at 80 deg., which would be saturated on cooling at 59

Fig. 1—Constant water-vapor pressure lines for silica gel, plotted against water content and gel temperature

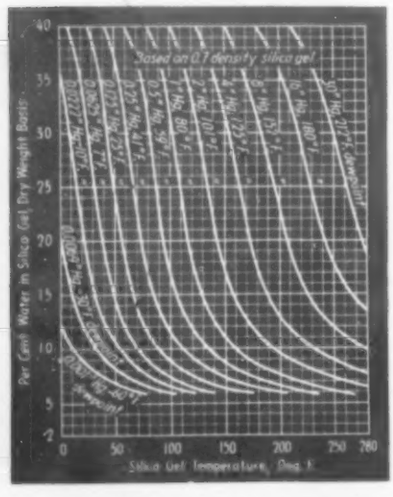
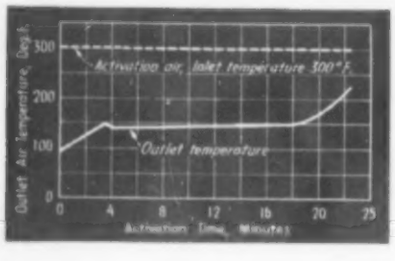


Fig. 2—Typical outlet air temperature curve for activation of silica gel



Comparison of Adsorption of Vapors by Silica Gel at 80 Deg. F.

Vapor	Boiling Point, Deg. F.	Vapor Pressure at 80 Deg. F., In. Hg	Per Cent by Weight in Gel at Equilibrium at Various Partial Pressures in Carrier Gas				
			0.5 in.	0.25 in.	0.1 in.	0.022 in.	50% sat.
Water	212	1	31.0	16.5	10.5	7.5	31.0
Benzene	177	4.1	20	17	13	7	26
Ethyl ether	95	22.1	13	10	7	3	18
Sulphur dioxide	14	121	3	1.5	1	...	21*
Hydrogen sulphide	−76	606	....	....	....	...	....
Carbon dioxide	−112	2,050	....	....	....	...	....

* Based on vapor concentration in gas of 50 per cent by volume.

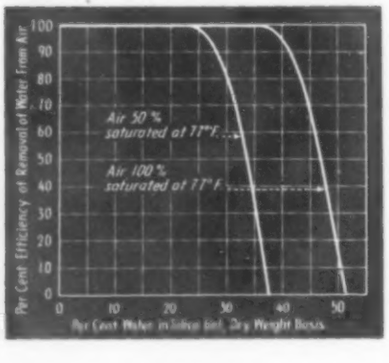
mately 0.5 in. Hg, and such air in contact with gel at 80 deg. would come to equilibrium with the gel at a water content of 31 lb. per 100 lb. gel, for at this water content the gel would have a vapor pressure of 0.5 in. Hg. the same as the air. Similarly with air at still lower vapor pressures at the same temperature. For example, 80 deg. air saturated at 7 deg. would have a vapor pressure of only 0.0625 in. Hg, and gel in equilibrium with such air would not adsorb beyond a moisture content of 8.8 lb. per 100 lb. gel. On the other hand, it should be noted that with air of the same dewpoint (moisture content), increasing the temperature of the gel results in a decrease in its adsorption capacity, since the same vapor pressure is attained with less adsorption.

Thus it is clear that increased adsorption occurs the lower the temperature and the greater the concentration of the vapor to be adsorbed, reaching a maximum at a given temperature when the gas is saturated with vapor.

If the gel is considered to be reactivated to a residual moisture content of 5 per cent, it will be evident that the useful concentration in the gel is the total minus this residual under the conditions of use.

An idea of the adsorptive capacity of silica gel for other vapors may be gained from the comparisons in the accompanying table of water vapor adsorption with that of benzene, ethyl ether, and sulphur dioxide. The vapor pressures of carbon dioxide and hydrogen sulphide at 80 deg. F. are shown in the table to indicate that they are in an elevated range approaching the

Fig. 3—Efficiency of adsorption of water vapor on silica gel at 77 deg. F. with air flow of 0.8 c.f.m. per lb. gel (Under isothermal conditions)

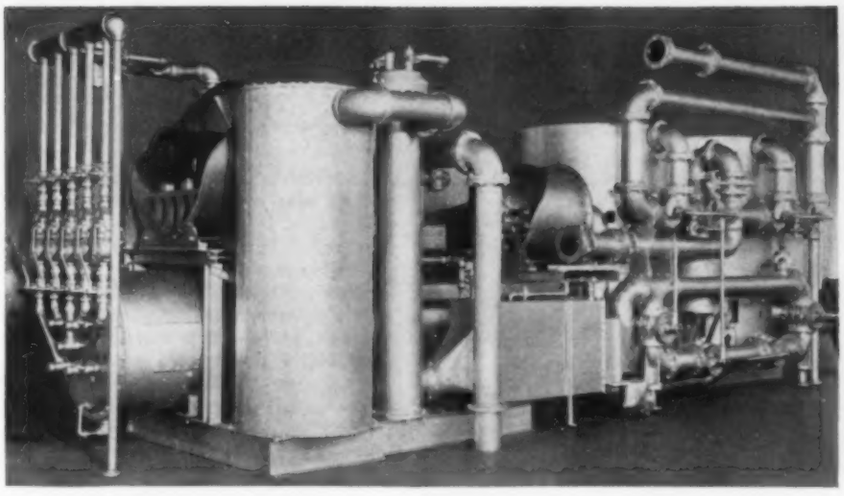

Air 50% saturated at 77° F.
Air 100% saturated at 77° F.
Per Cent Efficiency of Removal of Water From Air
Per Cent Water in Silica Gel, Dry Weight Basis

permanent gas state. The so-called permanent gases have extremely high vapor pressures, and they usually exist at low concentrations in air so that their corresponding pressure is low, therefore, the capacity of silica gel for them under such conditions is greatly reduced. Many of the corrosive gases and odors also have extremely high vapor pressures, and their partial pressure is usually low when contained in an atmosphere to an objectionable degree. These may be removed by adsorption on silica gel, but the capacity of the gel to hold them is extremely low, the affinity for them being due to partial condensation in the apex of the gel pores, and to their solution in the molecular layer of water in the pores on the surface of the silica.

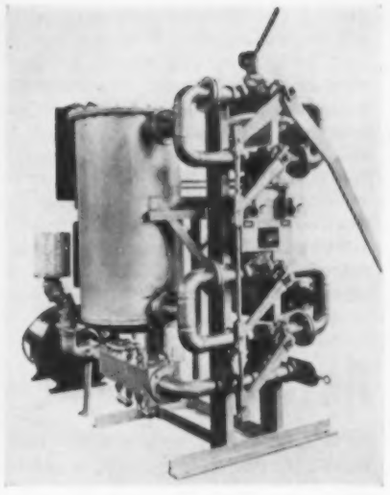
When vapor is adsorbed on silica gel or a similar adsorbent, heat is liberated equivalent to the latent heat of evaporation of the adsorbed liquid plus an additional amount of heat, known as the heat of wetting. The sum of the latent heat plus the heat of wetting is the heat of adsorption. During adsorption the latent heat of the vapor is transformed into sensible heat which is dissipated into the adsorbent, the metal of the adsorbent container, and the stripped gas mixture, and results in a rise in temperature.

The specific heat of silica gel is 0.2. The weight of 1 cu.ft. of the commercial product varies from 40 to 45 lb. depending upon the mesh size, the apparent density being between 0.65 and 0.73. Silica gel having lower or higher apparent densities can be readily made, and in some instances it has been found that specially prepared products are desirable.

After use, silica gel containing water may be regenerated or activated by subjecting it to an elevated temperature. The processes of adsorption and activation are completely reversible, so it is possible to use silica gel for an unlimited number of times without loss in efficiency or capacity. Activation may be accomplished by placing the silica gel in an oven for several hours or by blowing hot air through it until no more moisture is given off. A temperature of between 300 and 350 deg. F. is recommended for economical operation; however in some instances temperatures as low as 250 deg. F. may be used. Fig. 2 is typical of the outlet air temperature during the activation of a bed of silica gel when using hot air at 300 deg. F. The outlet tem- deg., has a vapor pressure of approxi-



C. M. Kemp inert gas producer, with silica gel adsorber for drying the gaseous products of combustion



Silica gel adsorption unit equipped for group operation of valves

perature of the air from the bed rises rapidly at the start, drops off slightly, and then remains fairly constant for the greater part of the activation period. When the water is practically all released, the outlet temperature begins to rise rapidly, and when a temperature in excess of 200 deg. F. has been reached, activation may be considered to be complete. Properly activated silica gel will contain from 5 to 6 per cent residual water, this is also the water content of the material as commercially supplied. The length of the activation period depends upon the rate at which the heat is supplied and may vary from a few minutes to several hours.

The amount of heat required to regenerate silica gel varies with the design of the equipment, for in addition to supplying the heat necessary to release the adsorbed compound from the gel, which is equivalent to the heat of adsorption, heat must be added for raising the temperature of the adsorbent bed and the adsorber, and to overcome radiation losses. In the usual type of equipment used for dehydrating air at atmospheric pressures, about 2,500 B.t.u. is required in activating air to release 1 lb. of adsorbed water, increasing in equipment used for treating gases at high pressures where the ratio of the weight of metal in the adsorber to the weight of silica gel is quite high. The activation air may be heated by any convenient source of heat such as electricity, steam coils, the direct products of combustion of well cleaned gas or clean waste heat. Activation may also be accomplished by subjecting the adsorber to a vacuum while heat is applied, either internally or externally or both, by means of electric elements or steam coils, but in practice the hot air method has been found to be more satisfactory and is normally recommended.

If the saturated silica gel contains valuable solvents other than water that are to be recovered, steam at a temperature of at least 275 deg. F., preferably in excess of 300 deg. F., should be passed through the bed. The effluent mixture of released solvent and escaping steam is condensed and fractionated, if necessary, to produce a pure product of the desired concentration. In the case of compounds that are miscible in water, approximately 3 lb. of sweeping steam is required per pound of adsorbed material, while only about 1 lb. is necessary when the product is not miscible in water. After desorption is completed, the gel must be activated for further use with hot air as above to drive out the sweeping steam that has been adsorbed, the weight of which corresponds to the equilibrium concentration for water in gel at a temperature which usually approaches the steam temperature.

Silica gel may be employed in either static or dynamic adsorption. An example of static adsorption is the drying of the air in containers used for shipping or storing equipment or products to prevent moisture damage by corrosion, mildew or mold (see *Chem. & Met.*, p. 775, Dec. 1939). In dynamic adsorption applications, the air or gas mixture containing the condensable vapors is passed through one or more layers or beds of silica gel. The curves in Fig. 3 show the results of dynamic adsorption of water vapor under the specific constant temperature conditions noted. As shown by the curves, the gel removes practically all of the water vapor until a break point is reached, at which the efficiency of removal begins to decrease. The efficiency of removal, after the break point, falls off until the gel is completely saturated, that is when the silica gel is in equilibrium with air having a moisture content corresponding to that of the entering air. Results in operation will vary from those shown as the several conditions influencing adsorption vary.

In commercial installations treating large volumes of air or gases at substantially atmospheric pressure, where

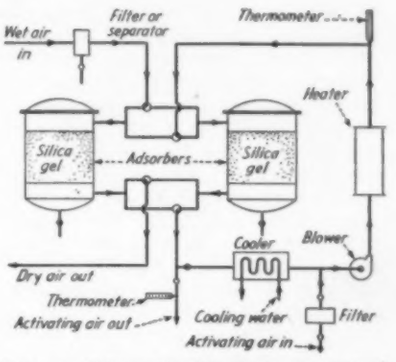


Fig. 4—Schematic diagram of typical two-adsorber silica gel unit

only a moderate degree of dryness is required as in comfort air conditioning systems, the rate of flow through the gel is often in excess of 10 cu. ft. of air or gas per minute per pound of silica gel, while in process work where extreme dryness is required and where the units may be operated at very high pressures, the rate of flow may be less than 1 cu. ft. per minute per pound.

In many industrial drying problems it is difficult to find conclusive data on which to base *dryness requirements*. In such cases the equipment is often designed to dry down to the minimum moisture content that might possibly be required, and to make provisions for admitting untreated moist air to the dry air stream so that the moisture content of the mixture may be varied until the optimum degree of dryness is determined. This can readily be accomplished in most instances by means of the silica gel process without materially increasing the weight of installed silica gel or the operating cost, the latter being practically proportional to weight of water adsorbed.

As the action of silica gel is practically instantaneous under dynamic adsorption conditions, the length of the adsorption period may be arbitrarily established. If automatic operation is

desired the cycle may be only a few minutes in length, yet in applications such as breathers on oil storage tanks or electrical equipment, the adsorption period may be of several weeks or even months duration. Equipment of the automatic or continuous manually operated type usually consists of two or more adsorbers, one of which is treating the air while the other is being activated. In some instances where extremely dry air is required the air being treated is passed through two or more adsorbers in series with intercoolers between them to remove the heat of adsorption, thereby improving both the efficiency and capacity of the silica gel in the second adsorber. In such cases it is often wise to cool the hot gel after activation down to the working temperature before it is returned to the adsorption part of the cycle.

Any desired volume of air or other gas may be dehydrated with silica gel at any pressure, down to dew points below minus 60 deg. F.

Activated Alumina Adsorption

By G. L. SIMPSON, vice president and general manager, Pittsburgh Lectrodryer Corp., Pittsburgh, Pa. **This material, a development of the last few years, has gone actively ahead in a wide variety of applications and is producing extremely low humidities.**

DRYING AIR, liquids and gases by means of activated alumina is accepted widely as a tool of industry. In connection with this activity, there is some demand for data on adsorptive properties under varying operating conditions. The manufacturers of activated alumina have published information on the total capacity of activated alumina and its practical capacity under some typical operating conditions. For example, its total capacity in 90 per cent saturated air is 20 to 25 per cent of its weight. When drying air, 90 per cent saturated and maintained at 30 deg. C., it will absorb 12 to 14 per cent of its weight of moisture while reducing the dew point to below −76 deg. C., i.e., to less than 0.0000008 gram per liter. Similar data (*Ind. Eng. Chem.*, July 1939, p. 866) are given on the drying of typical organic liquids under practical dynamic conditions.

At the present time few reliable or usable data relating to the performance of any adsorbent under a variety of practical conditions are available in the literature. This is because of the large number of variables which influence the capacity of an adsorbent under practical operating conditions. It will be made apparent that calculations on the performance of any adsorbent require the co-ordination of families of curves which involve all of the major variables; also that calculations from isolated laboratory data may lead to serious errors. An understanding of this may be obtained from a discussion of the influence of relative humidity, for, as is well known, the relative humidity of a gas being dried has as much (or more) influence on the capacity of adsorbents or absorbents as any of the other factors such as flow rate, contact time, adsorbent depth, surface exposed and particle size.

In drying a gas, heat is liberated as soon as the first traces of moisture are removed. As a result the relative humidity of the gas being dried is reduced rapidly in passing through the adsorbent. At the same time the capacity of the adsorbent to take up moisture is lowered because of the lower humidity. If the heat of adsorption is removed by cooling, the relative humidity will be proportionately increased. Therefore, the capacity of the adsorbent will depend upon the effectiveness of the cooling device. For example Derr has shown curves (*Ind. Eng. Chem.*, Apr. 1938, p. 384) in which air of several humidities and flow rates was dried with activated alumina with the adsorbent bed temperatures maintained between 90 and 100 deg. F. Substantially the same percentage of moisture was adsorbed in the activated alumina in each experiment while dry air was being produced. This does not show that relative humidity is of small importance; on the contrary, it shows that the same cooling device substantially compensated for the lower entering humidity and maintained the bed temperature close to the minimum stated.

In dehumidification equipment where high flow rates and shallow adsorbent beds are employed, the capacity of the adsorbent at low relative humidities is more nearly relevant to practical performance. More accurately, the rate of moisture removal from air of low relative humidity, rather than total capacity, is the important item. The data in the accompanying table compare the percentage moisture adsorbed by activated alumina and silica gel when exposed statically for several periods to air at 86 deg. F. and 2 mm. vapor pressure (6.3 per cent relative humidity).

Time, Hours	Activated Alumina Per Cent H_2O Adsorbed	Silica Ge Per Cent H_2O Adsorbed
2	1.00	0.90
4	1.75	1.60
7	2.20	2.30
24	2.75	3.20
72	3.50	4.20

The above example is selected because these static conditions give results comparable to that obtained in practical dehumidification equipment. (It is a fact that all commercial adsorbents used in shallow beds with high air flow rates adsorb only 2 to 3 per cent of their weight of moisture before the efficiency of moisture removal drops to a point where reactivation becomes necessary.)

The example also illustrates that the total capacities of adsorbents at high relative humidities have no relation to their capacities under operating dehumidification conditions. Therefore, the important part of an adsorbent system is not primarily the particular adsorbent but rather the equipment in which it is employed.

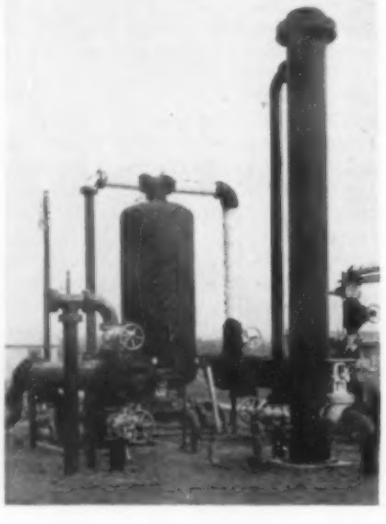
Of great practical importance to the engineer are certain factors which, if known with reasonable accuracy, contribute to the proper application of solid adsorption equipment.

Designers of this type of apparatus or the prospective purchaser should know as far as practical the correct values for these factors. Once the problem is clearly outlined and its boundaries marked, then the selection of the proper type and size to meet these needs may be done with assurance.

Factors affecting the economical application of solid adsorption for dehumidification of gases under pressure, include: (1) input dew point and temperature; (2) pressure at which the drying is to be done; (3) degree of dryness required; and (4) length of the adsorption period. Having established these factors the manufacturer of drying equipment is in a position to figure the type of machine best suited for economical operation, low maintenance and minimum investment.

1. *Input Dew Point*—The dew point of a gas is a measure of its absolute moisture content. The lower the dew point, the less the load of moisture delivered to the apparatus in unit time, other things being equal. When it is remembered that a gas with a dew point of 90 deg. F. has nearly twice the moisture content of one with a dew point of 70 deg. F., the importance

High pressure activated alumina adsorber for drying natural gas



of knowing the actual dew point within reasonable limits is emphasized.

Consider a case in point. Controlled atmosphere producers of the partial combustion type have aftercoolers to condense some of the moisture present. Adsorption dryers often follow, to obtain still drier gas. The temperature of the cooling water available has a considerable effect on the size of this dryer.

Again, when drying compressed gases, adequate aftercoolers and low temperature water contribute to reducing the load on subsequent dehumidifiers. Obviously, the use of cool water costing twice as much as readilly available warm water may result in the most economical installation. The effective use of cooling frequently permits the use of an adsorbent under its own most favorable conditions.

2. *Operating Pressure*—When a wet gas is compressed, then cooled, both the compressed volume and the weight of the water vapor are reduced. Naturally this will result in smaller drying apparatus. It rarely, if ever, pays to compress a gas merely to reduce the size of the subsequent drying apparatus. If, however, compression for other purposes is a part of the process, advantage may often be taken of this compression to reduce the cost of drying. On the other hand, the construction necessary to withstand the higher pressures increases the investment and there is a point beyond which it is not economical to go. For this reason drying is often done between the stages of multi-stage compression. Selection of the proper location of the dryer depends upon the pressure and the temperature of the gas after the intercoolers at each stage. Of course the gas must be then dried enough so that the later stages of compression do not raise its dew point above that desired in the final stage.

In high pressure equipment a small quantity of any adsorbent will dry a large volume of gas. For example, an activated alumina unit for drying gases continuously at 4,000 lb. pressure requires equipment weighing 75 times the weight of the activated alumina.

3. *Required Dryness*—Gases are dried for one of two reasons: (1) to prevent the condensation of moisture; and (2) to reduce the actual water vapor content. The reason for drying should be studied so that a sufficiently low, but not lower than necessary, dew point is specified.

For instance, in the prevention of hydrate formation in natural gas lines, it is the presence of liquid water in the lines that is objectionable. If hydrates can form at the temperature and pressure of the line, the gas should be dried to a dew point low enough to prevent condensation. The actual line temperature, and not the minimum weather temperature, is the controlling factor here.

Compressed gases are dried so that freeze-ups can not occur at expansion valves and also to prevent corrosion in the lines by liquid water. Here again the actual temperatures encountered set the requirements for dryness.

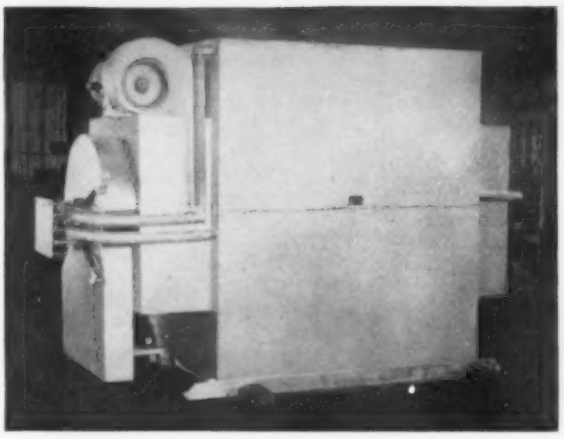
On the other hand, in some controlled atmosphere annealing, the important consideration is the quantitative relationship between the water vapor and the other gases of that atmosphere. By varying the nature and quantity of the constituents of such an atmosphere the gas may be made carburizing or decarburizing, oxidizing or reducing, or neutral. In actual practice these dew points may run from as high as 60 deg. F. to as low as −76 deg. F.

There are other applications, in the chemical industry, where the driest gas obtainable is needed either because the water vapor content may react to form undesired compounds or because its catalytic effects must be controlled.

Activated alumina is capable of producing the driest gas of any adsorbent suited for commercial use. This drying at high intensity allows desirable modifications in dehumidification as well as complete drying systems.

4. *Adsorption Period*—Solid adsorbents dry for a period, then must be shut down and reactivated. If time can be found to do this reactivation before the dryer is needed again, the investment in an additional adsorber is saved. Commercial equipment today is often built with dual adsorbers so that continuous drying may be obtained. It is common to design for 6 or 8 hours adsorption, with reactivation completed within a like time so that the change can be made manually once each work shift. In some applications, however, it may be desirable to extend this period to 24 hours or even a week to reduce the manual attention required. This necessarily increases the machine investment but may work an operating economy or convenience. Automatic operation is used in some cases simply because the manual attention saved is worth the cost of the extra equipment.

When dehumidifying air for industrial air conditioning, additional factors to those outlined above enter into the selection of the economical equipment. In such applications an inclosure is usually kept at some predetermined relative humidity. Here temperature control enters into the problem. But the dehumidification may be studied independently if the absolute humidity necessary is figured from the temperature and relative humidity desired.



Large water-cooled activated alumina dehumidifier for industrial air conditioning, employing 15-lb. steam

These additional factors involve: (1) the amount of fresh air required; (2) the amount of "infiltration"; (3) the moisture load from the process; (4) the moisture load from population; and (5) the outside design conditions selected.

A word or two about some of these factors. Codes or good practice direct the number of cubic feet of fresh air per person introduced for breathing purposes. Odors and noxious fumes, or dust removal may require the venting of considerable air. The actual requirements here should be studied to insure adequate ventilation without burdening the dehumidifier with excess moisture from the outdoor atmosphere.

"Infiltration" is used here loosely to include the moisture which enters the inclosure through changes of air other than the forced ventilation and also the moisture which enters by diffusion through the inclosing walls. Where a low water vapor pressure is being maintained, diffusion becomes of considerable magnitude. Special precautions in the construction of the room, with the sealing of the walls with nonpermeable material, are of great benefit in reducing the machine load.

By understanding clearly the requirements in a dehumidification application, with quantitative knowledge of the factors which affect the load at hand, the application may be made with assurance that the results will be satisfactory if well designed and well built apparatus is installed.

In summary, activated alumina, like all adsorbents or absorbents, is merely a part of any drying system. The capacities of practical sorbents at low vapor pressures are quite similar. As a result, equipment in which the sorbent works becomes the deciding factor in choosing how dehumidification is to be accomplished. The selection of the conditions under which the adsorbent is to work is important to obtaining economical installation and operating costs.

Other Dehydration Methods

By *EDITORIAL STAFF*. In addition to the methods of separating gas-vapor mixtures which have been discussed, there are several others of importance for special applications; these are briefly described here with some indicated fields of application.

High pressure installation for dehydration of natural gas at 250 lb. gage; towers contain 1,000 lb. of Drierite

LIQUID DEHUMIDIFYING AGENTS are easily circulated so that one unit may be designed for absorption and one for regeneration thus permitting continuous operation.

Diethylene Glycol—The principal use of this hygroscopic organic liquid in connection with conditioning is the dehydration of natural gas. Several recent installations serve as examples of what can be accomplished with the compound. Contact with gases is established in bubble towers in which scrubbers at the base remove oil and mist extractors at the top prevent glycol loss. In one of the first plants to use this system about 5 g.p.m. of glycol were used to absorb the moisture from a peak capacity of 20,000,000 cu.ft. of gas at 715 lb. Enough water is removed to lower the dewpoint of the gas from 65 or 70 deg. F. to an average of 28 deg. F. Regeneration is accomplished in a still operating at 25 lb. and 295 deg. F. Boiling point of the glycol at this pressure is 473 deg. F. so no glycol is detectable in the water effluent of the reconditioning still.

Another installation, operating at 339 lb. gage, reduces the dewpoint from 73 to 23 deg. F. Solution pumping rate is 8 g.p.m. and average solution loss over an 11-month period was 0.052 gal. per million cu.ft. (measured at 16.4 lb. abs. pressure).

This chemical was used in an interesting combination in a recent installation in Kansas. The circulating solution contains 7-8 per cent monoethanolamine, 75-80 per cent diethylene glycol and 12-16 per cent water by volume. This mixture not only lowers the natural gas dewpoint to 0 deg. F. but also lowers the H_2S content from 20 to 0.05 grains per 100 cu.ft. Losses in the first four months of operation were 190 gal. of glycol and 30 gal. of amine, representing a cost of 25 cents per million cu.ft. of gas treated.

Triethylene Glycol—Several manufacturers of air conditioning equipment are considering triethylene glycol for air dehumidification purposes. Because of its low vapor pressure and high boiling point, losses are comparatively low. Lower dewpoints are obtainable with triethylene glycol than with calcium chloride or lithium chloride solutions. Triethylene glycol is also being considered for the dehydration of blast furnace air and plant designs based on its use have been submitted by equipment companies to steel company prospects for this type of equipment.

Hygroscopic compounds, such as triethylene glycol, suitable for use in air conditioning equipment have a vapor pressure high enough to entail some loss due to vapors being carried out with the dehydrated air. A recent patent (U.S.P. 2,192,126) sets forth a system for reducing this loss. The vapors, being hygroscopic, can be removed by the use of a second spray chamber involving a more dilute solution of the same compound. By using a 95 per cent solution of the glycol in the dehumidifier and 60 per cent in a second spray chamber, less than one tenth as much glycol is lost as would be if the air were discharged after contact with the 95 per cent solution.

Sulphuric and Phosphoric Acids—Appropriately enough sulphuric is used in dehydrating burner gases and air in the contact process of sulphuric manufacture. Gases must be dry or acid fume will cause trouble. The disadvantage of this acid is its corrosive action. Phosphoric acid is often used for laboratory desiccation because of smaller tendency to react with gases which combine with sulphuric acid. Water vapor pressures of the two acids at 90 per cent concentration and 30 deg. C. are 0.012 mm. of mercury for sulphuric as against 2.0 for phosphoric. For comparison, these values at the same temperature are 13 mm. for 40 per cent calcium chloride and 12 mm. for 82 per cent glycerin solutions. However, heats of dilution of the acids are much greater than for the other two solutions.

Solid Absorbents—There are some laboratory and industrial applications of solid absorbents. As with calcium chloride, these solids absorb both by capillary action and by hydration.

One of the more important of this class of compound is anhydrous calcium sulphate (Drierite) which absorbs moisture to form the hemihydrate. The compound is used in high pressure installations, in telephone cables to prevent short circuits, in drying refrigerant gases and in space drying in vaults, cabinets, tool chests and so forth.

Numerous other compounds are used but these are of limited interest in gas conditioning. They are frequently used as laboratory desiccants. In this group are anhydrous barium perchlorate, anhydrous magnesium perchlorate, fused alkali hydroxides, zinc halides and copper sulphate.

Isothermal Compression—Thermodynamically the isothermal compression process results in no change in internal energy. The entire amount of work done on the system produces heat, which must be removed continually to keep the temperature from rising. Actually it is not possible to provide for continuous heat transfer to this extent and the process may be approached only in multiple-stage compressors with a large number of intercoolers.

In a saturated gas-vapor mixture the total pressure is the sum of the partial pressure of the constitutents; $P_o = p_v + p_g$. If the total pressure is increased tenfold and the temperature remains constant, p_v will not increase* (because it depends only on temperature); so we have: $10\ P_o = p_v + p'_g$, where $p'_g = 10\ p_g + 9\ p_v$.

According to Raoult's law the mol fraction of vapor remaining in the mixture is $p_v/10\ P_o$. That is 0.1 of the original vapor; therefore, 0.9 of it must have condensed. Now if this liquid is removed and the gas expanded at constant temperature, the final gas will have a relative humidity of 10 per cent with respect to the vapor instead of 100 per cent as in the original mixture.

As mentioned previously, dehumidification in this manner cannot actually be accomplished by an isothermal process; but with ample intercooling the same final result may be obtained. Thus as far as the gas-vapor mixture is concerned, the process may be considered isothermal. Incidentally, the condensing vapor absorbs a large amount of heat (its latent heat) thus producing a cycle more nearly isothermal than can be obtained with a non-condensable gas.

Intentional use is made of the above principles in the separation of butanes and propanes from natural gas, and unintentional use in ordinary air compression, where the problem of removing the condensed water vapor is usually present.

*At higher pressures (50 atm.) vapor pressure will increase due to Poynting effect.

Choice of Dehydration Methods

By *JAMES C. PATTERSON*, Manager Dehydration Div., Carrier Corp., Syracuse, N. Y.

The effect of such factors as gas and power costs, availability of water and steam, climatic conditions, desired temperature and humidity and investment cost determine the choice of dehumidification and dehydration methods for a given installation.

THERE IS NO one best method of dehumidification which is suitable to all applications. It is practical, however, to set up and discuss the principal factors which influence the choice of method as between refrigeration on the one hand, and dehydration with solid adsorbents or liquid absorbents on the other.

Furthermore, since the terms *dehumidification* and *dehydration* both denote abstraction of water, the question may arise as to the distinction between the two, so this should be cleared up at the outset. This distinction may be said to lie in the medium which causes the abstraction of water, thus:

Dehumidification is generally associated with refrigeration, by which, water vapor is condensed out of air or other gases in its passage over a cold surface or through a cold spray maintained below the dewpoint. The extent of dehumidification by this method is therefore dependent upon the extent of temperature reduction.

Dehydration, on the other hand, is generally associated with equipment containing certain desiccants of the regenerative type, which have the ability literally to extract water vapor from air or other gases brought in contact with such desiccants without resort to low temperature cooling.

Because the primary function of dehydration equipment deals with the removal of water vapor from air and other gases—and also because there is less familiarity with dehydration as compared with the conventional refrigeration—the former will be discussed first and in greater detail.

There are two basic methods of dehydration: with solid adsorbents, and with liquid absorbents.

Silica gel and activated alumina for water vapor adsorption, and activated carbon for solvent vapors, are the most widely used of the solid adsorbents. These substances are extremely porous and have the property of picking up and condensing vapors on their surfaces and internally, with no change in physical structure. Adsorption continues until the vapor pressure of the condensed liquid in the capillaries approaches the partial pressure of the vapor in the surrounding atmosphere.

The liquid solution type of absorbents functions somewhat similarly. Lithium chloride brine is the most widely used type. Such a brine in contact with moist air of higher vapor pressure picks up moisture from the air until the increasing vapor pressure of the solution, which is changed physically in the absorption process, approaches the decreasing partial pressure of moisture in the air. With air of lower vapor pressure, of course, the reverse action takes place, with humidification of the air.

Essentially, the choice of method, as between the solid and liquid types, depends upon: (1) the degree of dehydration that is to be accomplished, (2) kind of application, (3) temperature and cost of available water, (4) availability and cost of manufactured or natural gas and the availability and cost of high or low pressure steam, and (5) geographic and climatic conditions.

In general, it may be stated that the smaller the quantity of outside air to be dehydrated in proportion to the total quantity of air to be circulated and the greater the extent of dehydration required, the more favorable becomes the solid adsorption type. By the same token, the larger the quantity of outside air in proportion to the total and the smaller the extent of dehydration required, the more favorable becomes the liquid absorption type.

Conditions for Dehydration

In either case, the dehydration method of removing water vapor from air or other gases is of greatest value where: (1) it is desirable to maintain humidity conditions independently of dry bulb temperature conditions; (2) it is essential to provide precise control of the absolute moisture content in air directed to or surrounding an industrial process; (3) there exists a comparatively large percentage of latent heat load to the total load; (4) cold tap or well water is available for cooling purposes; (5) it is practical to take advantage of operating economies through the use of gas or steam heat.

Since the principal function of dehydration is to produce dry air and maintain dewpoint temperatures independently of cooling, this method must be qualified *economically* as well as technically, in the light of that limited function, before it can be properly selected instead of refrigeration.

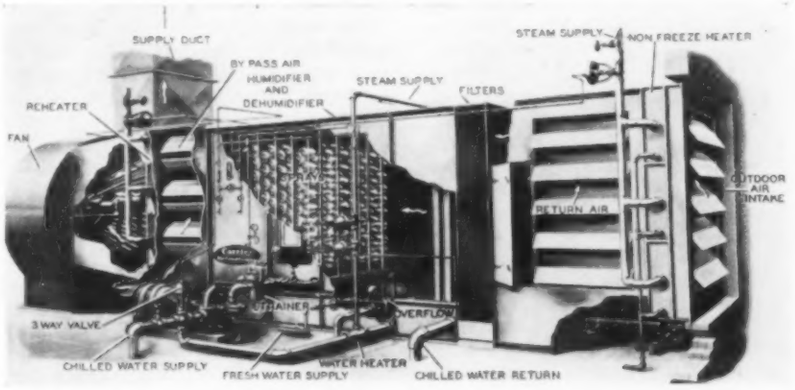
For example, when the extent of dehumidification required for any one specific application need not go beyond that obtainable as a *byproduct* of low temperature cooling, the conventional refrigeration system is likely to be lower in first cost as compared with a dehydration system designed for the same duty. Dehydration could not be economically qualified for such applications unless its higher first cost could be compensated by lower operating cost resulting from favorable water temperature conditions coupled with low cost natural gas or steam.

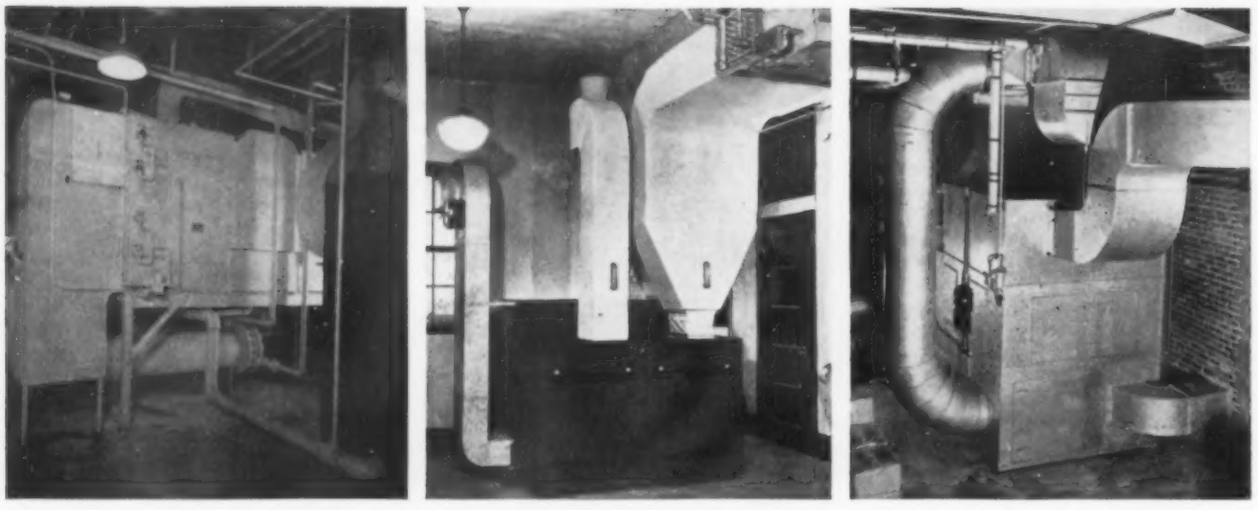
On the other hand, when the extent of dehumidification must provide for the maintenance of a constant inside absolute humidity against comparatively large internal moisture sources, coupled with higher than usual outside moisture design conditions, the dehydration system is likely to be lower in *overall* cost than the refrigeration system designed for the same duty. It should be mentioned, however, that it is not uncommon to find that a dehydration job is a "premium" job insofar as first cost is concerned.

There is also the question: How much of the dehumidifying should be accomplished by dehydration equipment? For instance, there are many cases where it will be more economical to remove a part of the latent heat by the cooling medium (cold water or refrigeration) and to use dehydration for the removal of the remainder. Geographic and climatic conditions are important considerations in such cases.

Because of the necessity of weighing these and other variables in the light of conditions of use, it is impractical to set up *fixed rules* regarding the initial cost of the dehydration method as compared to the refrigeration method. Yet, and without giving effect to decreasing production costs of dehydration equipment *per se* (due to

Schematic drawing of Carrier central station air conditioning system





From left to right are dehydration installations employing lithium chloride, silica gel and activated alumina; the equipment was supplied by Surface Combustion Corp., Bryant Heater Co. and Pittsburgh Lectrodryer Corp., respectively

standardization and increasing volume), there are certain influencing factors which definitely reflect upon such cost comparisons. These are:

1. *Kind of Application*—In cases where the sensible heat load varies over wide limits and where it is desirable to maintain control of relative humidity within narrow limits, dehydration is generally the more favorable.

In cases where the conditions of use require the maintenance of dewpoint temperature below 43 deg. F., or the maintenance of relative humidities over a range of between 10 and 50 per cent at dry bulb temperatures above 80 or below 60 deg. F., dehydration becomes favorable.

For the maintenance of dewpoints below 37 deg. F., dehydration is practically an essential.

2. *Water Temperature*—It is practical to use water for all sensible heat removal in combination with dehydration when the temperature of the available water is at least 15 deg. F. below the dry bulb temperature to be maintained within a room or in connection with an industrial process.

With decreasing water temperatures, the scope of application increases, and the economic advantage of using dehydration equipment becomes more apparent.

In the absence of a sufficiently cool water supply for temperature control purposes, the evaporative cooling principle may be employed, or more generally, mechanical refrigeration would be used to take up all or any part of the sensible heat load which cannot be removed economically by water.

3. *Utility Service*—The relative unit costs of gas, steam, electricity, and water coupled with the extent of utilization, bear directly on cost of operation and, in many cases, are the deciding factors.

Where the unit cost of gas or steam (high versus low pressure) is low as compared with electric power, the operating costs of dehydration can be capitalized to good advantage.

In comparing the total cost of utility service as required for the dehydration method with that required for the refrigeration method, consideration should be given to all demand charges as may apply.

Where cost of water is high or quantity limited, both methods are adaptable to water cooling towers or evaporative condensers. The water requirements are approximately the same for both methods.

The seasonal load factors for both gas and electric utilities may be improved by using gas, or steam operated dehydration equipment.

To summarize this phase of the subject, it may be stated that the dehydration method—first, as particularly adapted to the removal of water vapor under conditions of high latent heat load and low sensible heat load, and second, as a user of energy in the form of gas or steam—can be evaluated in terms of the total annual cost of providing dehumidification as compared with an equal amount of dehumidification by the conventional mechanical refrigeration method.

Refrigeration Systems

As with dehydration, there are two basic types of refrigeration. These are the compression type system and the absorption type system. It is not within the scope of this discussion however, to include a presentation of the latter.

A compression system is almost universally used for those applications which do not require the maintenance of low humidities or which do not demand the independent control features in manner and extent as generally associated with dehydration. It should be understood however, that it is practical to provide independent control of humidity and temperature with a more costly compression type refrigeration system through the use of automatically controlled *reheat*.

The compression system permits the choice between several types as well as the kind of energy that may be used for the particular application. For the compressor system, the following types are available: (1) Reciprocating compressors driven by electric motors, by gas engines and occasionally by steam engines; (2) rotary compressors driven by same motive power as for the reciprocating type; (3) centrifugal compressors driven by electric motors, steam turbines or gas engines; (4) steam jet (vacuum) type, using steam as motive power.

The proper selection as to type will depend upon: the amount of tonnage of refrigeration required, the degree of temperature reduction, and comparative overall costs. Furthermore, the influencing factors previously outlined with particular respect to dehydration, bear on the choice with respect to refrigeration.

For example, the centrifugal or steam jet type produces chilled water and ordinarily would be utilized for applications requiring 100 tons of refrigeration and more. For the lower temperature levels, the centrifugal type would become more favorable than the steam jet type. The choice as between the use of steam and electricity for either type would depend upon the analysis of total annual cost of owning and operating, with due consideration to collateral advantages and disadvantages.

Moreover, there is a choice as to method of dehumidifying by these several types of compression refrigeration. That is, condensation may be accomplished by spraying chilled water in direct contact with air, or indirectly by means of cold surface made up of spiral wound or plate finned air cooling coils, or a combination of both spray and coils.

Because the chilled water spray type

of dehumidfier saturates the leaving air more effectively, it is almost invariably selected for those industrial applications requiring precise control of dewpoints within narrow limits. The lowest practical dewpoint however, would be at 40 deg. F. For lower dewpoints, the addition of a brine spray stage or dehydration equipment would be required. In such cases, the latter is likely to be the more desirable choice from an operating and overall cost standpoint.

With the cold surface coil type, the dewpoint is of course depressed below the dry bulb temperature of the leaving air. The extent of this depression however, varies with the design of the coil and its bypass characteristics, and the practical temperature range through which condensation takes place. This type would usually be selected for those applications where reasonable fluctuations in dewpoints or relative humidity is not a serious consideration, or where it is advisable to obtain local control of variable conditions at scattered points.

This is also the type cooling system that is used in combination with dehydration equipment to give independent control of humidity and temperature. In such cases the surface coils need have only sufficient capacity to produce cooling *above* the dewpoint and thus approach the maximum in operating efficiency.

There are many dehumidification problems where various types of refrigeration are normally used, and which involve the maintenance of high relative humidities (above 70 per cent) combined with subnormal dry bulb temperatures. This is an exclusive field for refrigeration.

To summarize this phase: The refrigeration method, first, as conventionally adapted to the simultaneous control of humidity and temperature at normal levels, or as particularly adapted to maintaining higher than normal humidities at subnormal temperatures, and second, as adapted to the use of electricity, steam or gas prime movers for motive power, can be evaluated in terms of total annual cost with an equal amount of dehumidification by the dehydration method.

It may be concluded then, that both the dehydration method and the refrigeration method have their individual favorable spheres of application with respect to dehumidification, and that the choice is essentially dependent upon the influencing factors discussed.

Humidification Processes

By EDITORIAL STAFF. **Earlier articles in the series on processes involving gas-vapor relations were concerned with the separation of gases from condensable vapors. The converse problem of humidification is encountered in a variety of applications where a liquid is vaporized into an air or gas stream to cool the liquid or the gas, or to separate the liquid from a solution or a solid.**

THERE are eight types of vaporization operations that should be considered here as related to the psychrometric study of gas-vapor mixtures. First, for simplicity, it should be explained that the term "humidification" is used not only to refer to the vaporization of water into a gas, but may be considered also to describe the vaporization of any volatile liquid into air or any other gas. In general, with proper corrections for differences in the properties, what is said here about vaporization processes involving water may also be applied to other volatile liquids. In the terms of the air conditioning engineer, humidification means an increase in the dewpoint of the mixture with respect to whatever kind of vapor is being considered.

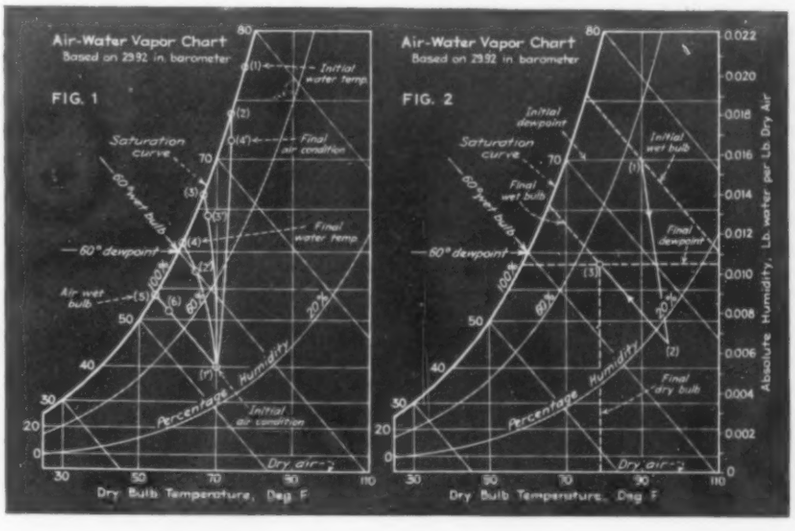
Depending on the reason for humidifying the gas, there are four sorts of humidifying operations: (1) Those in which it is desired to cool the liquid; (2) those in which the gas is to be cooled; (3) those where the desired end is a gas of higher absolute vapor content; (4) those in which the aim is to decrease the amount of liquid contained in a solid or in a solution. In the first group are two principal applications: Water cooling ponds and towers, and evaporative-type coolers for process cooling and condensing. The second type of operation is encountered chiefly in evaporative coolers for air. In the third group are included air-conditioning humidifiers and saturators for process gases. Finally, the last class includes dryers for solids in which air is used to sweep out the vapor; regenerators for dehydrating solutions; and the operations comprising the regenerative steps for solid adsorbents.

All of these operations depend on the psychrometric properties of the liquid and the gas concerned, and all are similar in principle—the differences being chiefly in the source of the heat which must be supplied for vaporization of the liquid. In the most common case the heat comes both from the gas and from the liquid, in which case both the liquid and the gas are cooled, the latter being humidified also. However, it is possible to take all of the heat from the liquid so as to heat as well as to humidify the gas, or to take all of the heat from the gas so as to cool and humidify the gas adiabatically. This last occurs when air is humidified in an air washer, with unheated, recirculated water.

Water Cooling Ponds and Towers—If water at a relatively high temperature is brought in contact with air having a wet bulb temperature lower than the water, the water will be cooled, and will eventually reach a temperature close to the wet bulb temperature of the air if sufficient air is swept over the water for a sufficient time. Equipment for cooling water in this way is generally operated to cool the water to a temperature somewhat below the dry bulb temperature of the air, to within 5 to 10 deg. of the wet bulb temperature of the air. Fig. 1 illustrates on a psychrometric chart the changes taking place in the air and the water as they are brought into contact. The several points on the saturation curve represent the progressively lower temperatures of the water as it travels downward through a packed tower through which air is flowing upward.

Fig. 1 — Chart illustrating theoretical changes in air and water conditions in passing through a cooling tower

Fig. 2 — Schematic diagram of dehydration path, followed by adiabatic cooling below the cooling water temperature



The initial air, meeting water which is below its dry bulb temperature, is cooled and humidified. The initial air thus supplies part of the latent heat of vaporization of the water, but as the air progresses upward through the tower, meeting water at higher and higher temperatures, and emerging finally at a temperature higher than the initial and nearly saturated, the final effect is to force the water to supply all of its own latent heat (approximately 1,000 B.t.u. for each pound going into the air stream), plus the sensible heat of the air temperature rise. If the contact time is long enough (i.e., the tower is tall enough) the air will leave near the dry bulb of the initial water, and the water will leave at a temperature near the wet bulb of the entering air. Practically, however, it will never reach the wet bulb.

With air at the same wet bulb temperature, but at different dry bulb temperatures, the effect in any case is for the water to approach the same wet bulb temperature, but it will be clear from a consideration of the chart that more air will be required for a given amount of water cooling as its dry bulb decreases.

Unfortunately, design of water-cooling equipment of this type is still empirical as the coefficients of heat and moisture transfer must be determined experimentally. (See articles on cooling tower design by Edward Simons, *Chem. & Met.*, Feb., Mar. and Apr., 1939, pp. 83, 146, 209, resp.). However, the psychrometric chart does furnish useful information, particularly in indicating the type of change in equilibrium conditions that will occur for various changes in the initial conditions of the water and air.

Types of Coolers

Water cooling by evaporative action takes place in cooling ponds, atmospheric cooling towers and mechanical draft towers. Pond cooling requires the largest amount of space, an atmospheric tower less, and a mechanical draft tower still less. In all three types about 1 lb. of water is lost for 1,000 B.t.u. of cooling, while according to Bischof (*Trans.* A.S.M.E., Jan. 1939) the additional loss of water, owing to driftage, will be of the order of 3.5-5 per cent of the water circulated for ponds, 1-1.5 per cent for atmospheric, and 0.2 to 0.5 per cent for mechanical draft towers. Spray ponds, unless large enough to keep down driftage loss, are generally provided with a surrounding louver fence to permit wind motion, but restrain entrainment losses. Atmospheric towers are provided with flat decks to present a large water surface and increase the time the water remains in contact with the air, yet avoid undue resistance to the cross wind. Mechanical draft towers are either of the spray type, without packing, or packed with slats over which the water is distributed, either forced or induced draft being provided by a fan. More cooling work can be accomplished per cubic foot of tower by the mechanical type, but where suitable wind conditions exist, the atmospheric type is generally preferred, owing to its lower initial and operating cost.

The evaporative condenser, which has recently become an important adjunct to refrigeration and air conditioning equipment, is in effect a combination of mechanical draft cooling tower and condenser, in which condenser tubes are substituted for the slat surface of the tower. Water is sprayed over the tubes (and is generally recirculated), the wetted tubes being subjected to a blast of air from a fan. Evaporative cooling of the water on the tubes makes possible a condensing temperature approaching (but, of course, never reaching) the wet bulb rather than the dry bulb temperature of the air. Actually, most of the condenser cooling is accomplished by evaporation of the water, although in cooler weather direct air cooling without spray water is often practised. Compared with straight water cooling of the condenser without a cooling tower, with an evaporative condenser the water consumption is reduced 90-95 per cent.

Evaporative Air Coolers—Where low humidity exists, as in the southwestern part of the United States, there is considerable use of adiabatic saturation of the air for comfort cooling purposes. If air is brought into contact with a spray of recirculated water, after a fairly short time the water will attain a temperature equal to the wet bulb temperature of the air, at point (5) on Fig. 1. Continuing the spraying of this water will result in increasing the humidity of the air along its wet bulb (adiabatic saturation) line, bringing the air to some final condition of lower dry bulb and higher humidity as at point (6) on Fig. 1. Another use of adiabatic saturation is in cooling air dehumidified by adsorption below the temperature of the available cooling water. For this purpose the air is dehydrated excessively and then partially rehumidified to secure the desired dry bulb reduction. Fig. 2 shows such a cycle. Point (1) is the initial condition, point (2) the excessively dehydrated condition obtained with the available cooling water, and point (3) the final condition after adiabatic cooling.

Humidifiers—As long as water is at a temperature equal to or higher than the dewpoint of the air with which it is brought in contact, it will evaporate into the air if the latter is not saturated, which is to say that as long as the partial pressure of water in the air is less than the vapor pressure of the water, diffusion of water vapor will continue into the air. However, since the driving force tending toward vapor pressure equilibrium is the vapor pressure difference, humidification proceeds more rapidly as the water temperature increases above the dewpoint of the air. Usually in humidifiers the water is heated to a temperature above the dry bulb temperature of the air as in condition (1) on Fig. 1, so that the air will be both heated and humidified. Any means of establishing intimate contact of air and water for a sufficient time will suffice. In air conditioning a spray washer, with water heated by steam, is the most usual method. Steam jets or pans of heated water in the air stream may also be used, as well as water sprayed finely into the conditioned space by a spray or mechanical atomizing device. The last two methods are also sometimes used industrially to effect humidification coincident with a certain amount of evaporative cooling in the summer. Similar principles hold, of course, regardless of the liquid vaporized, and the carrier gas.

Dryers — Although another article discusses the application of psychrometrics to air dryers, this type of humidification should be noted here. In such a dryer heat supply is generally provided almost entirely by the air, although radiation from the air heating coils may play a part, and in some cases heat may be applied directly to the material, with the air used only to sweep the vapor away. From the standpoint of the material, drying is dehumidification, but it results in humidification of the air, which will continue to pick up moisture as long as the vapor pressure of the water in the material is less than the partial pressure in the air.

Dessicant Regeneration

It is clear that the vapor pressure of water in the material is not necessarily equal to that of free water at the same temperature. For example, in the drying (regeneration) of solid adsorbents such as silica gel, the water is closely held by capillarity and must be heated to a relatively high temperature to produce an appreciable vapor pressure. This is ordinarily accomplished with hot air, or with steam in the case of activated carbon. In the drying of hygroscopic solutions, such as lithium or calcium chloride, a similar effect of vapor pressure depression is found, the vapor pressure being less at a given temperature as the solution is more concentrated. Thus, when the hot solution is sprayed into air or brought into contact in a tower, its water will be vaporized, but only until the still lower vapor pressure of the more concentrated solution which is produced approaches the partial pressure of the air. A high range psychrometric chart can be used to portray this cycle, using as the saturation curve in any instance the appropriate one of a series of vapor pressure curves for the different concentrations of the hydroscopic solution.

Compression Equipment

By Z. G. *DEUTSCH*, Consulting Chemical and Mechanical Engineer, New York. **Compressors used industrially for refrigeration and other gas compression operations are here compared and a new chart is presented to show their fields of use.**

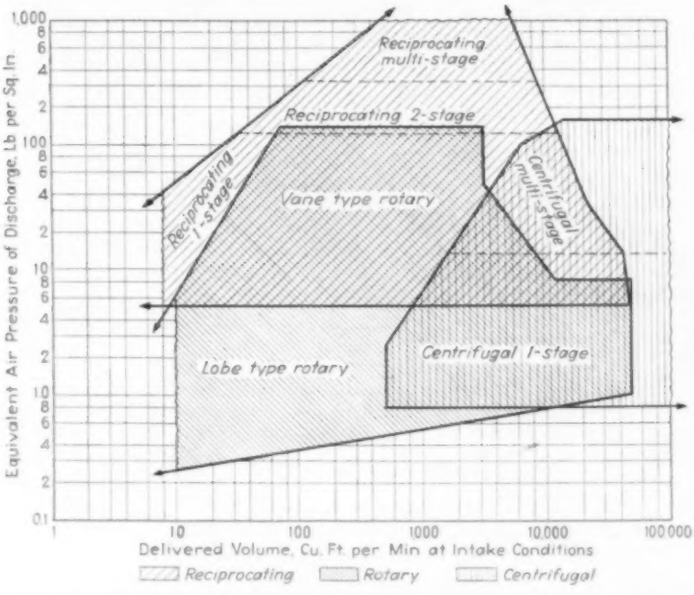


Chart showing the range of discharge pressures and displacements commonly met with various types of compressors, referred to atmospheric air inlet

IN THE MANY types of processes wherein gases, vapors or gas-vapor mixtures are handled in order to effect separations, purifications, reactions, etc., efficient compression and movement of the fluids is always of importance. Occasionally efficient compression is of prime importance. Gases and vapors flow from regions of higher pressure to regions of lower pressure, according to well understood and well formulated laws. For inducing flow against most practical resistances, pressure changes of lower magnitude are the rule. Fans and blowers are the usual names given to "compressors" used essentially for inducing flow. For those processes which are the subject of this section and involve refrigeration, adsorption and absorption, a gas pressure change of greater magnitude is often involved. This article confines itself to a brief discussion of the compressors used industrially for such larger compressions.

Equipment for creating these terminal pressure differences in gases and vapors has developed and become available in a variety of forms. The piston-and-cylinder reciprocating compressor type is probably the oldest with the exception of the almost obsolete bellows. Axial- and radial-flow centrifugal machines are a development of the present. Various forms of positive displacement rotary compressors are almost all of quite recent origin. An ancient form, which has but recently come into prominence in commercial refrigeration, is the steam jet or fluid jet type of apparatus, sometimes also called the thermo-compressor.

For the purposes of this brief discussion all compression equipment is grouped into four general divisions: (1) reciprocating displacement; (2) rotary displacement; (3) centrifugal (radial and axial); and (4) jet.

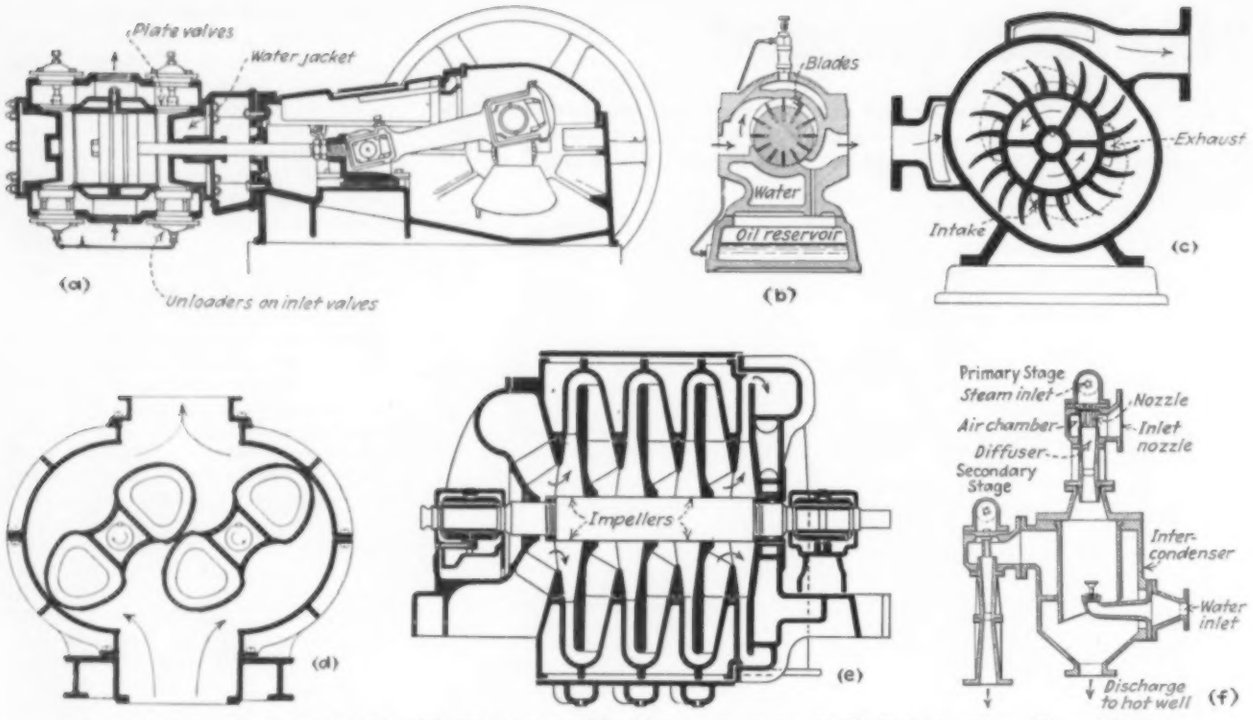
The first two are often called "positive displacement," when compared to the last two. Several divisions of the first are: horizontal, vertical, duplex, double acting, uniflow, etc. Several divisions of the second are: sliding vane, hydraulic piston, cycloidal, eccentric roller, etc. Several divisions of the third group are: axial flow, radial flow, shrouded and open impellor, etc. In the fourth division there are as yet no well-defined and accepted types. For a concise description and clear diagram of the forms of the foregoing types, the reader is referred to a group of articles in the fluid flow section published in *Chem. & Met.*, May 1937. All types by themselves are in use for single, double and multiple stage compression. Occasionally a multiple stage compression installation will consist of stages in each of two or more of these types.

Each of these four general types and each of their subtypes, has a field of application wherein it is most profitable. The fields overlap with one or more of the other types over a broad range whenever anything less than *all* controlling factors are considered. The accompanying chart considers only pressure and volume.

In the fields of application where pressure changes are large, such as where the absolute discharge pressure is over 20 times the absolute suction pressure, and where the initial gas density is not especially low, the reciprocating machines are substantially without competition in sizes under about 2,000 or 2,500 hp. Likewise in the field of extremely low density gases such as encountered in vacuum processes well below 1 or 2 in. Hg absolute, the jet compressor is in almost any but the very smallest capacities, without competition. With gases of higher and highest densities, at moderate pressure ratios, and power inputs of over 2,000 hp., the centrifugal machines are almost without competition. For less extreme conditions the reasons for the choice of a definite representative of one of the four types are concerned with many more factors than merely power, pressure or pressure rise and density. The kind of power which is available, the type of driver suitable to this power, space limitations, commercial factors, as well as economy considerations, usually govern.

Because of the large number of factors involved, and because of the wide range of conditions under which compression equipment is applicable, it is practically impossible to state a common set of categories into which any type of compressor can be niched. Performance of compressors is changed by the density of the fluid being handled. This a much more important factor with centrifugal than with the reciprocating or positive rotary types of machines. Consequently centrifugal machines are usually based on an "equivalent" discharge pressure. This term is analogous to the "feet-of-head" in the centrifugal pump field. It is, briefly, the discharge pressure of a centrifugal machine at its rated operating speed, when the gas at the inlet is of the same density (and same ratio of specific heats) as normal atmospheric air. Thus, for example, a 5-lb. equivalent air-pressure machine, designed to handle illuminating gas having a specific gravity relative to air of 0.5, will at its rated operating condition, have a discharge pressure of only (about) 2½ lb. per square inch. This is entirely

Certain types of equipment are found in more than one kind of gas conditioning operation. In order to avoid duplicating the description of these more general types, therefore, the section starting at this point deals briefly with the four equipment classes which are of more general application. Included are compression equipment, heat transfer equipment, gas cleaning equipment and gas-liquid contactors.—Editor.



Typical compressor types including (a) reciprocating, (b) sliding vane rotary, (c) fluid piston rotary, (d) cycloidal or lobe type rotary, (e) centrifugal and (f) steam jet

analogous to the 100-ft. head centrifugal pump, whose bourdon gage discharge pressure would be 30 lb. per square inch when pumping gasoline, 69 lb. per square inch when pumping carbon tetrachloride, and 590 lb. per square inch when pumping mercury. The term "equivalent air pressure" is adopted in this field because it is so much more convenient than feet-of-gas would be.

In the diagram on page 317 an effort has been made to delineate the fields of operation for the first three types of compressors from the standpoint only of pressure and of volume handled by single units. Other characteristics of compressors and factors affected by these characteristics were not given any weight in the preparation of this chart. The fourth, or jet type, is commonly rated on the basis of weight of suction fluid handled, rather than volume. Since it frequently operates under high pressure ratios and occasionally under moderately high suction density, plotting on this same type of chart would give an aberrated impression of its range so it is omitted.

The outlines of the several areas indicated on this chart can be considered as extremes. The number of installations of each type is greatest for the pressure and volume conditions near the center of each of the areas. There are a few rare installations of each type entirely outside of the areas indicated. Furthermore, this chart applies only to industrial equipment. Domestic equipment and low pressure equipment such as fans have been omitted entirely.

The maximum power which it is practical to put into the driver of these compressors is important and has to some extent determined the right-hand boundary of the reciprocating compression region. In turbine-driven centrifugal compressors operating at very high speeds, such a boundary is beyond the diagram and turbines of suitable capacity have already been built, being used for driving electric generators.

The accompanying table lists some relevant factors affecting the choice of compressors when considered for many (although not all) usual applications. An idea of the suitable type of drivers is obtainable from the columns indicating the ranges of speed and horsepower. This table is far from all-inclusive. It has been assembled in order to give "thumb-nail biographies" of the principal types of compressors.

From the standpoint of power efficiency, the reciprocating type compressor is at a disadvantage for large volumes of low density gas or vapors, as the mechanical losses and particularly the losses by throttling through valves bear a high ratio to the total work accomplished. Most designs of positive rotary compressors avoid valve loss, but their mechanical losses under certain circumstances may bear a high ratio to the total work accomplished. The power efficiency of the reciprocating machine is generally advantageous over a wider range of capacities and pressures than are those of its competitors. The rotary is high in efficiency at its design capacity or particular operating condition. The centrifugal machine has moderately high power efficiency for large volumes and fairly low pressure ratios, although an axial flow machine is efficient in a narrow range only. These properties make feasible the use of centrifugals with low pressure refrigerants. The jet compressor is lowest in average power efficiency but in its field of very low density gas is probably as good or better than other compressor types can be made to be.

In large capacity (over about 40 hp.) refrigeration applications, which are typical of one-component processes, two types of compressors predominate. The reciprocating type is confined to those refrigerants whose vapor pressure is

Ranges of Application of Principal Compressor Types

	Power Hp.		Inlet Gas Density Lb. per Cu. Ft.		Rotative Speeds R.P.M.		Inlet Pressure		Inlet Volume Single Unit C.F.M.		Compression Ratio	
Main Type	Low	High	Low	High	Low	High	Low	High	Low[4]	High	Lowest	Highest
Reciprocating displacement	1	2,500	0.02	50	30	400	29 in. vac.	any	10	40,000	1.8	1,000±[1]
Rotary displacement	1	1,000	0.02	50	30	600	28 in. vac.[2]	100 lb. gage	5	50,000	1.8	5 per stage
Centrifugal	50	any	0.004	15	1,800	30,000	0.2 in. Hg abs.	any[3]	500	any 120,000	1.07	8
Jet	—	[6]	0.000+	any	—	—	"microns"	20 lb. gage	—	any[5]	1.2	10 per stage

[1] 10 per stage is max.; 5 per stage usual. [2] Higher vac. for lamp and tube evacuation. [3] About 500 highest to date. [4] 0.5 to 10 lb. motive fluid per lb. suction fluid. [5] Depends on physical size limitations only. [6] Lowest commercial.

high through the range of temperature involved. Centrifugal compressors are used for the lower-vapor-pressure, higher-density refrigerants. For example, butane and most refrigerants with higher vapor pressure are most commonly handled with reciprocating compressors. Water vapor, trichlorethylene, dichlorethylene and the di- and monofluor chlormethanes are commonly handled with centrifugal machines. The jet type of compressor with water vapor as the refrigerant is expanding in application, particularly at temperatures of 40-50 deg. F.

The chemical industry much more frequently handles mixtures of gases and vapors. The four types of compressors have properties and characteristics, the importance of which frequently overshadows considerations of cost or efficiency. With an especially corrosive gas, a reciprocating piston type machine, with its machined internal surfaces in intimate contact with the gas, may be impossible to use. Also there may be available no lubricant for the internal parts which will not contaminate the gas or be rendered ineffective by it.

Use of the jet compressor may not be feasible because direct mixing of motive fluid with suction fluid or with the other vapors or adsorbents involved in a process may not be permissible.

The liquid-sealed rotary positive displacement machine of the Nash Hytor (liquid piston) type is often the most practical for handling highly corrosive gas. This is most frequently true in smaller volumes. These machines, because of their possible slow speed, may be made out of resistant materials having relatively low mechanical properties. All that is needed is an inert liquid or one which, if not inert, can be disposed of, reconditioned or reactivated at reasonably low cost.

Occasionally the requirements of gas conditioning equipment may be such as to be benefited by pulsating flow or, vice versa, by the steadiest possible flow. The jet gives by far the steadiest flow conditions; axial, then radial flow centrifugal equipment the next; with rotary positive displacement and reciprocating positive displacement machines last, depending on the pressure ratios and speeds.

The reciprocating positive displacement type of machine and some of the rotary machines must, except with highly specialized designs, have some form of liquid lubricant in contact with the gas. Contamination of the gases or vapors by the lubricant can be reduced to a remarkably low minimum but can never be eliminated entirely, with reasonable maintenance expense. Compared to this, one of the rotary positive displacement types depends 100 per cent for its operation on a sealing fluid which can also present a contamination problem. Some rotary positive displacement machines require neither sealing fluid nor lubricant in contact with the gas and this property may dictate the use of this type of machine in certain conditions.

Centrifugal machines almost without exception require neither lubricant nor sealing fluid, except the shaft seals. Ingenious and acceptably simple designs are available which avoid contact between gas and sealant.

The ejector type of compressor requires admixing with another vapor or gas. This can be an advantage or disadvantage. For example, it is not unusual, when one gas must be mixed with another, for one of the two gases to be available at a high pressure, while the second requires compression. Under such conditions the ejector is almost ideal because pressure reduction of the high pressure gas, pressure boosting of the low pressure gas and intimate mixing are all made to take place in one simple, compact and moderately efficient unit.

From the standpoint of maintenance and attendance expense, a general rule, applying to most, non-severe cases might state that per thousand cubic feet of gas handled, the jet is most favorable, the centrifugal next, most rotaries next and the reciprocating compressor last. Almost enough exceptions to invalidate this rule, are to be found.

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Heat Transfer Surfaces

By *CARLYLE M. ASHLEY*, Director of Development, Carrier Corp., Syracuse, N. Y.

Finned tubes of one kind or another are often first choice in the conditioning of gases and air because they satisfy most of the heat transfer requirements.

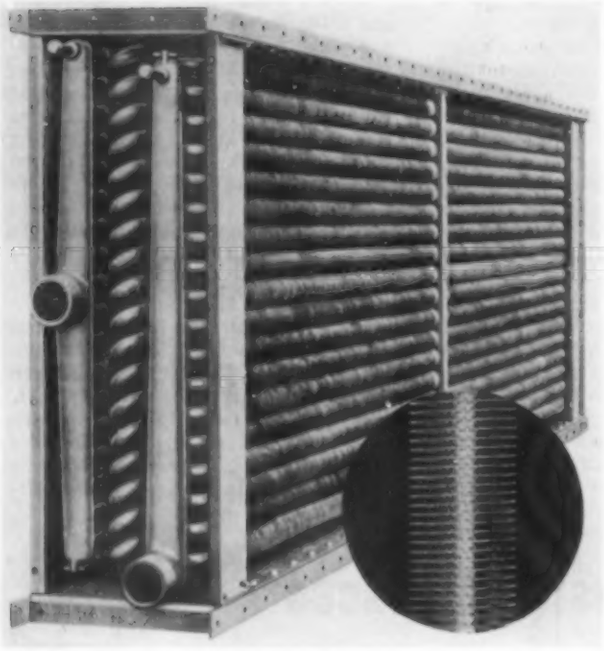
IN CHOOSING the heat transfer surface or interchanger to suit the needs of a particular application, we may list a number of factors of general importance which may influence the choice. Among the more important of these are: (1) cost, (2) resistance to fluid flow, i. e. pressure drop, (3) space occupied, (4) volume of fluid required to fill the interchangers, (5) resistance to corrosion, (6) ease of cleaning, and (7) danger of damage due to freezing.

The relation of these factors to equipment choice can best be shown by a study of specific problems of heat transfer. Heat transfer between a gas and a liquid, and more specifically between water and air, should serve as a convenient starting point.

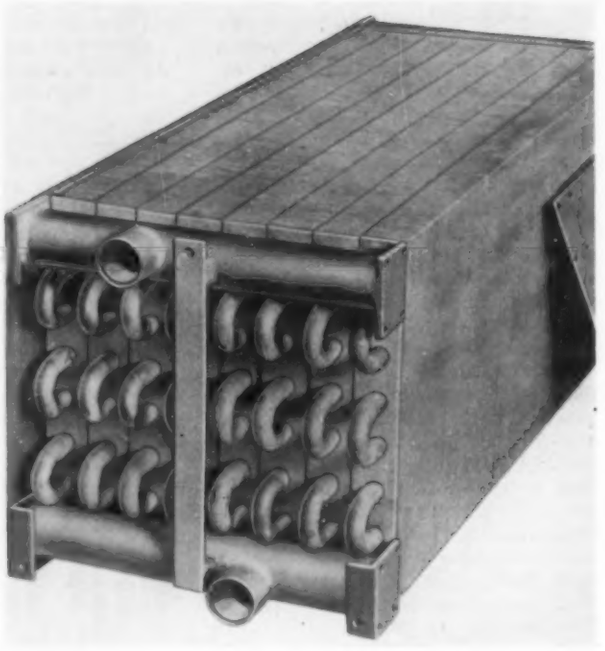
As is well known, the heat transfer to a fluid which is in turbulent motion is limited by a slow moving film adjacent to the heat transfer surface. In this film the flow is non-turbulent and is parallel to the surface, thus requiring the heat to be transferred through the film by conduction. This so-called "film transfer" is a function not alone of the conductivity of the fluid, but of the velocity along the surface, the density of the fluid, the viscosity of the fluid, and the character of the heat transfer surface. For air the film transfer varies from a value of less than 1 B.t.u. per hr. per sq. ft. per deg. F. difference in temperature, for certain types of surface with gravity convection of air, to about 20 B.t.u. per. hr. with very high air velocities. Usual values with forced air circulation lie between 5 and 15 B.t.u. per hr. On the other hand, the film transfer for water in turbulent flow varies between limits of about 100 and 1,200 B.t.u. per hr. with usual values around 300 to 800 B.t.u. A preferred form of heat transfer surface for this application is a pipe coil consisting of a series of tubes across which the air flows and through which the water flows in a direction generally at right angles to the air. Since the heat must pass in series through the external and internal films and the metal of the tube, the low film transfer of the air forms a choke point for heat flow.

To make the prime surface of the tubing more effective, extended surface is added on the air side in the form of fins. The added cost is only for the fins, and yet the total air side transfer of the coil is increased in approximately the same order as the increase of the surface. The fins also introduce a new element of resistance to heat flow in the metal of the fins. With an all prime surface coil the conductivity of the tube is too great to be a factor in the problem, but with fins the amount of surface is increased and the cross-section is decreased. Metals having a high heat conductivity such as copper and aluminum are therefore preferred for fins and the thickness in relation to the size of the fin becomes a factor of importance. If a large amount of finned surface is added the choke point is transferred from the air film to the water film and metal until finally a point is reached beyond which a further extension of the fin is not economical. Accompanying illustrations show some of the features of finned coils for this type of transfer.

Spirally wound finned surface finds its chief application as a blast coil



Fins on the tubes of this water-air heat exchanger consist of a soldered spiral winding as shown in detail in the inset



Here the fins consist of plates in which holes are punched for the tubes, which are expanded or soldered in place

with relatively high air velocities (300 to 800 ft. per min.). It is usually characterized by a high air film transfer and a high metal transfer. The plate fin surface overlaps the field of the spiral fin surface but finds its preferred application where extremely low resistance to air flow is required as with gravity convection or where the flow is induced by ejector action. For this service the tubes are spaced farther apart than is in accordance with good design practice with the spiral fin construction.

Face velocity is also kept very low. Under such a condition the air film transfer is low and thus more extended surface is economically justified which fits in admirably with the wide tube spacing required. With close fin spacings a point is finally reached as the velocity is reduced where the transfer is entirely by conduction between the metal and air. Further lowering of the velocity has no further effect on the transfer. Thus, it is possible to get reasonably good film transfers (3 to 6 B.t.u. per hr.) with extremely low resistance to air flow. By decreasing the size of tubing used for the coil it is possible to decrease the spacing as well, and thus to decrease the thickness of the fin as well as the tube, making a less expensive surface. However, where a coil of some size is to be used the circuiting of the water becomes more and more of a problem as the size of the tube is decreased. Thus, for all but very small coils most of the tubing is from $\frac{1}{2}$ to $\frac{3}{4}$-in. in outside diameter.

Cost of a coil to meet a given application will be less the higher the air and water velocities used since the film transfers increase with increase of velocity. However, the increased velocity results in an increase of resistance to flow which may result in an objectionable operating cost, may increase the cost of other parts of the system, or may cause noise. For this reason specifications usually set a limit on the pressure drop on both the air and water side.

Consideration should always be given to proper selection of materials to resist corrosion even though no special corrosion problem is involved. Usually an all copper and brass surface is preferred, and with a casing properly protected by galvanizing and painting, but there are cases where other materials may be substituted to advantage.

Where the water system is closed it is usually not necessary to make provisions to clean the water side, but where well water or other water which may bear silt or scale is used it may prove desirable to provide access through a removable header. If the air is dirty there may be a collection of dirt on the surface. Most of the dirt will collect on the entering side and can be removed by brushing, or with a jet of air or water. In some cases, however, it has proved desirable to divide the coil so as to provide access to each row.

Where a water coil is in an air stream which may go below freezing some means of protecting it must be worked out. Either a non-freeze solution must be used, or else the coil must be drained. Unfortunately, the usual water coil does not drain readily. Its water circuits zigzag back and forth from end to end of the coil so that the coil must be maintained level. Pitching it either way will trap water in some portion of the coil. But the small tubes do not drain readily due to capillary hold-up of water and due to the effect of slight unavoidable differences in level. To be safe against freezing, therefore, it is advisable either to blow out the coil with compressed air, or to give the coil a slope toward one end.

It is fortunate that the film transfer of steam and of evaporating and condensing refrigerants is in the same range as that of water as it permits the use of the same type of surface with all of these fluids.

Besides the uses of this finned interchanger as an air cooler and heater, and as a refrigerant evaporator and condenser, it also has many uses where the surface is wet. Where used as a cooler or evaporator the surface may be below the dewpoint of the surrounding air, resulting in condensation of moisture on the surface. For other applications water may be sprayed on the surface. For a cooler or evaporator this may be done to provide extra scrubbing action, to provide continuous humidity control or to remove frost (spraying brine) when the surface is below freezing. Another important application of sprayed surfaces is that of evaporative condensers. The spiral fin surface is particularly suited to application as a sprayed surface due to its tendency to redistribute water from row to row and due to its relatively low build-up of resistance. When high air velocities are maintained through wetted coils the water tends to carry through and requires the use of eliminators. When the coil surface is wet the transfer of heat is related to the

difference in total heat between the air and the surface instead of the difference in temperature.

The same type of surface is suitable for use with gases other than air in chemical process work. The problem of transfer from one liquid to another, or from liquid to evaporating liquid or condensing vapor usually requires a rather different solution.

In refrigerant condensers it is usually economical to use some extended surface, even though the condensing film transfer rate is fairly high. In this case, however, the fins must be low and thick so as to keep the metal transfer high. The use of fins increases the capacity of a given size of condenser and at the same time by shortening each circuit permits the use of higher water velocities with the same pressure drop.

In interchangers, cooling water by refrigerant evaporation, the same considerations govern as in condensers. Another important reason for the use of fins is to reduce the required charge of refrigerant, which is frequently a factor of importance in the total cost of the cooler. Besides this the more compact surface results in a higher refrigerant film transfer. In a recently introduced line of refrigerating machines both condenser and water cooler were with fins extruded from the tube itself. The fins were so short that the ends could be belled to the diameter of the fin, thus making possible the individual removal of each tube from the tube sheets. Results obtained were beyond theoretical expectations.

Condensers and water coolers are of four primary types: (1) shell and tube construction with tubes between two tube sheets and water usually through the tubes; (2) shell and tube construction with one tube sheet and return bends on other end; (3) shell and coil construction, either with coil with return bends or wound in a spiral or helix; and (4) double pipe construction. Where cleanable tubes are required the first type is preferred although the second may be used.

Liquid to liquid interchangers take a wide variety of forms. Where one of the liquids has a high viscosity and low conductivity, as for instance, oil, the use of extended surface may be indicated using a shell and tube interchanger or a shell and coil. Another approach is through the use of thin passages for the viscous liquid so that the heat transfer by conduction is high. This may be in the form of a double pipe interchanger or a plate interchanger. The latter is particularly well adapted to uses requiring a low pressure drop.

Where the film transfer of both fluids is high, it is customary to use prime surface either in a double tube, coil and tube, or shell and tube interchanger. However, where the cost of the construction is high, fins on one or both sides are economically justified.

Gas-Cleaning Equipment

By *EDITORIAL STAFF*. Regardless of the season, whether gas is humidified or dehumidified, cooled or heated, one part of a conditioning system is always the same. That one element which functions both summer and winter is cleaning equipment. Various types are described briefly.

IN INDUSTRIAL PLANTS all gases, including air, are contaminated to some extent by dust, grit and dirt; by fumes, smokes, soot and odors; germs, bacteria, pollens and spores. And conditioning, as the name implies, means the elimination of a large percentage of these undesirables as a matter of health, nuisance elimination, avoidance of fouling of air conditioning equipment and, sometimes, recovery of valuable materials.

For the purposes of our discussion here, the methods of gas and air cleaning are separated into two divisions: gas-liquid contactors and dry dust collectors. The first of these two sections, because of the industrial importance of gas-liquid contacting equipment, will be covered in another article of this report, and so will only be mentioned here.

Most commonly encountered of the liquid contactors is the spray chamber which is capable of removing some dusts, bacteria, odors and so forth, but little smoke, if present. Some dirt not caught by the spray is eliminated from the air stream by impingement on the wetted eliminator baffles.

Two other types of apparatus used in the field of air conditioning are plate contactors and packed towers. In both cases gases are washed by exposing them to large areas of wetted surfaces which trap dirt and dusts.

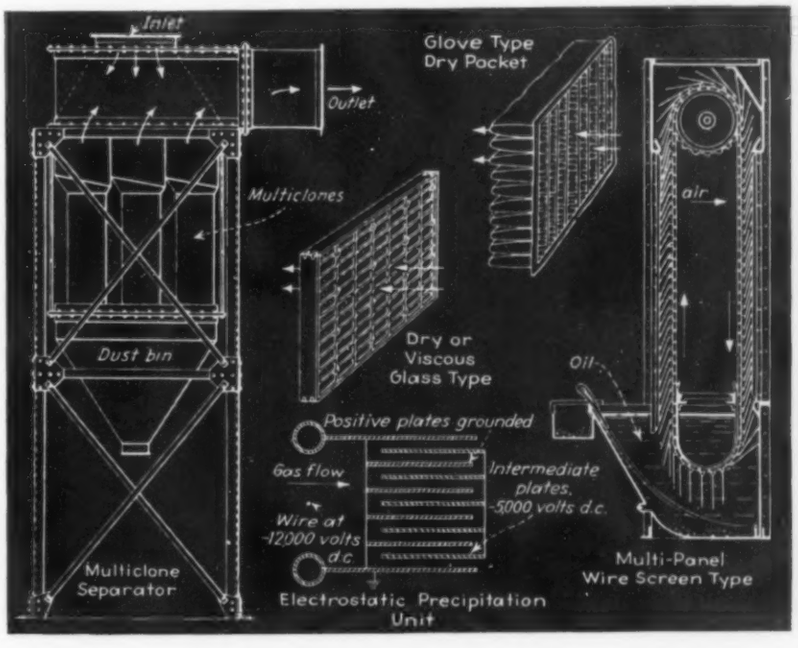
Other methods used industrially are wet cyclones, mechanical scrubbers and bubble contactors. Wet cyclones, such as the Pease-Anthony and the Schneible types, have rotating sprays and curtains of water which entrap the dusts and fumes and carry them out. Mechanical scrubbers of the disintegrator and Feld types act similarly but disperse large quantities of water mechanically. Bubble contactors may have one bubble cap plate, for example, as in the Bartlett-Hayward or they may have many plates as in a rectifying column.

Dry Dust Collectors

Settling—Simplest of all methods of dust collection are settling chambers in which gravity removes the particles. Applications of this mode of separation are limited, however, as the lower size limit is about 100 microns diameter. Accelerated settling may be accomplished by various devices of the cyclone type. Theoretical considerations in cyclone design show that radius of the circular path should be small and that velocity should be high. These observations are the reason for the design of the multiple cyclone dust collector shown in an accompanying illustration.

Electrostatic Precipitation — Heavy dust loadings are generally reduced industrially by some form of settling device, followed by a cleaning up of the

Diagrammatic representation of typical air and gas-cleaning equipment



exit gases with a Cottrell electrostatic precipitator. This method is most effective in the control and recovery of fine dusts, smokes and fumes. For the requirements of light dust loadings met in air conditioning, a comparatively recent development has made electrostatic precipitation also suitable for air cleaning and there seems to be no lower limit to the size of smokes, fumes and other particles which may be removed by this method. The Precipitron unit, see diagram, consists essentially of an ionizing unit, collector cell and power pack. Air or gas to be cleaned enters the unit and the particles accumulate a charge. The charged particles are then attracted to collector plates, give up their charges and are held by adhesion. Voltages are supplied by a power pack using 110 a.c. and 2,400 c.f.m. of gas requires about 75 watts. Precipitrons are standardized and almost any gas flow may be handled by using one or several units.

Filtration—Simplest of all methods of gas cleaning is passage of the stream through some porous medium. Fabric or fibrous, and viscous, are the two classifications of filter media. In the first, layers of cloth, porous paper or woven or felted fabrics serve to catch the dust and dirt. Fibrous materials usually consist of pads of mineral, glass or vegetable fibers. Viscous filters consist of relatively coarse mineral or metal threads coated with a liquid material to which dirt and other matter will adhere as the air or gas passes through.

Foreign matter is removed from air streams by either the "labyrinth" or "flypaper" method or a combination of the two. In the former, the air passes through so many devious twists and turns that most of the dust impinges on a surface to which it adheres. The so-called "flypaper" method implies a coated area on which a viscous coating is applied. Any particle of dust impinging on this coating is retained.

Older types of dry filters are cleaned by vacuum cleaner or washed, but the more recent installations use the throw-away type which are inexpensive enough to discard and replace as they become unusable. Such units may be fastened together, either in a bank or a series of V's, to make a filter of almost any capacity. Design of the unit should allow for air velocity of not more than 400 ft. per min. and a resistance to flow of not more than 0.25 in. of water.

The continuously washed, viscous coated filter shown in the accompanying illustration consists of a curtain of screens moving continuously on an endless belt. At the bottom, the screens are washed by passage through the liquid and at the same time pick up enough of the liquid to act as a viscous coating on the next trip around. This type is relatively expensive and is used for high capacity installations of 50,000 c.f.m. or more or where the use factor is high.

Liquid-Gas Contactors

By *H. F. JOHNSTONE*, Professor of Chemical Engineering, University of Illinois, Urbana, Ill. **There are a number of types of liquid-gas contactors which accomplish humidification and dehumidification by (a) liquid droplets moving through gas, (b) gas moving over wetted surfaces or (c) gas bubbles released below liquid surface. These are described and compared in the following pages.**

IN THE BROAD SENSE the terms *humidification* and *dehumidification* refer, respectively, to the processes of increasing and decreasing the concentration of any condensable constituent of a gas. This paper will describe liquid-gas contacting equipment for carrying out these processes where change in vapor pressure (rather than gas absorption) is the primary consideration. In this instance humidification is accomplished by evaporation into the gas stream and dehumidification by condensation on droplets or on a wet surface.

The mechanism of vapor pressure change is similar to desorption and absorption in that material must be transferred by molecular diffusion across a gas film adjacent to the liquid surface, and by eddy diffusion through the bulk of the carrier gas. However, it differs in that large quantities of latent heat must be transferred as well as sensible heat in the same or opposite direction. This is true because the transfer of heat depends on the magnitude and direction of the temperature gradient; and the transfer of vapor similarly on vapor pressure gradient.

Among the factors which influence diffusional processes, the shape of the interface and the interfacial velocity are among the most important. These are also the two that can be varied the most in the design of equipment used to bring gases and liquids in contact with each other. Classification, therefore, will naturally be made along these lines.

From the standpoint of surfaces, three types are immediately apparent: (a) liquid droplets moving through the gas, (b) wetted surfaces usually established by some sort of packing, and (c) bubble surfaces produced by release of the gas under the surface of the liquid. The effect of other variables, which cannot be changed independently of the type of surface, requires a restriction to the general application of each type. Each should be used only in the field in which it has unique advantages.

Spray type humidifiers are commonly used in air conditioning equipment (See cut). Experiments[5] have shown that the coefficient of mass transfer through the gas film is high as long as the drop is moving at an appreciable velocity relative to the gas. Since the surface per unit volume of liquid varies inversely as the diameter of the drop, large surfaces can only be obtained by fine atomization of the liquid. This may be accomplished by spraying the liquid through nozzles operated at high pressures, or by discharging the liquid onto a whirling disk, or wheel. Unfortunately, the kinetic energy of the small droplets is rapidly lost due to the resistance to their passage through the gas. Consequently, droplets under 400 microns in diameter soon decelerate even when propelled at high initial velocities. Furthermore, if the spray contains droplets of widely differing sizes, coalescence takes place due to the larger drops sweeping out the smaller ones. As a result of these effects the volume coefficient of mass transfer for a simple spray decreases rapidly with distance in front of the nozzles. For this reason such sprays have not been adopted where high efficiency is required. A more careful study on the part of the manufacturers of spray nozzles should overcome some of the disadvantages of simple spray chambers. At the present time spray humidifiers usually consist of horizontal nozzles set at relatively short distances in front of baffles. Undoubtedly the action of the wetted surfaces of the latter contributes much to the humidification efficiency of the spray chamber.

Recently, considerable attention has been given to the wet cyclone chambers (See cut). In this modification of the spray tower the droplets are formed by nozzles located at the center of the cyclone. The gases enter the chamber tangentially, thereby setting up a centrifugal force which hurls even the smallest droplets through the gas at high velocities. Although considerable coalescence of droplets probably takes place here also, with properly designed nozzles the absorption and humidification coefficients are surprisingly high. Tests[2] on two large scrubbers of this type have indicated that gases at 450 deg. F. may be brought to within a few per cent of their saturation. Each of these scrubbers handled approximately 50,000 cu. ft. of hot gas per minute and were 10 ft. in diameter and 20 ft. high. The water rate was 50 to 100 gal. per min. to each scrubber. The great advantage of the wet cyclone, of course, is the simplicity of construction and the low draft loss associated with the passage of the gas through the empty chamber. Removal of extremely fine dust and tar particles can be accomplished simultaneously with the humidification.[6]

Although spray towers have not been used for dehumidification of gases,

chiefly because of the absence of surfaces which could serve to absorb heat continuously, it is possible that they could serve as such by the introduction of a large amount of liquid precooled to a temperature considerably below the wet bulb of the gases. In general, such towers operate with high liquid-to-gas ratios in any case because of the low hold-up. The high heat transfer coefficient which exists around small particles passing through a gas should promote high efficiency.

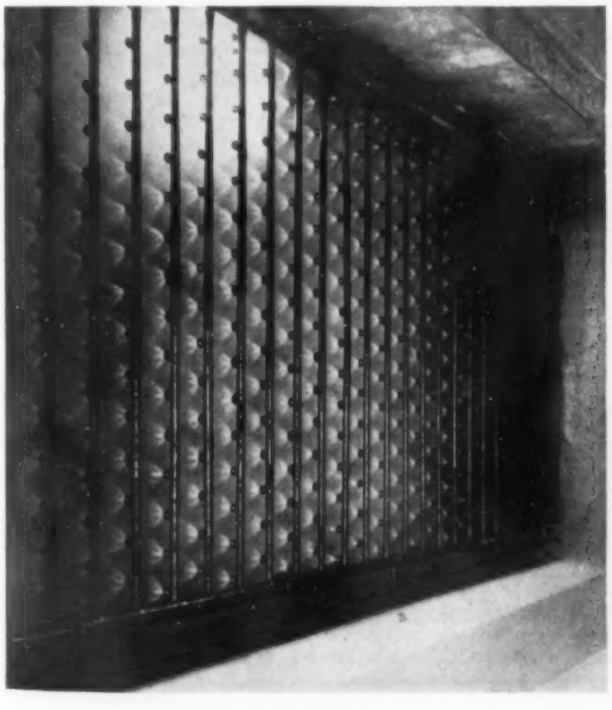
The opportunities for variations in design are even greater when wetted surfaces are used for gas conditioning equipment. A number of new types of tower packing have appeared in recent years which are highly efficient from the standpoint of having high transfer coefficients, large surfaces per unit volume, high liquid and gas rates, low resistance to gas flow, and low weights per cubic foot.[5,7] In general, the small packing used for absorption towers is not as suitable for conditioning of large quantities of gases as the more open grid packing. The latter has been thoroughly studied both in this country[8] and abroad and has been adopted in England for the difficult operation of absorbing sulphur dioxide from hot, dust laden flue gases.[2] Humidification of the gases in these scrubbers is nearly 100 per cent in spite of a travel of only a few feet. Draft loss is less than 1 in. of water at gas velocities of 10 ft. per sec., or more. Optimum spacing of the grids has been proposed for maximum efficiency at minimum power requirements. Although wood is usually used for grid packing, ceramic grids with patented drip points are available.

Slat packed towers have long been used for water cooling. The cooling is accomplished by humidification of air having a wet bulb temperature lower than the temperature of the water. Cooling towers may be operated either with natural draft or with forced convection. The operating and design characteristics of these was presented in the recent papers by Simons in *Chem. & Met.*[9] In the common splash deck tower the overall heat transfer coefficient depends upon the wind velocity as well as on certain tower dimensions including the angle of the louvers, the tower height, the number of bays, deck spacing, thickness of the deck slats and the width against the wind of the posts and ties. In forced convection cooling towers streamlining of the slats is recommended in order to obtain low resistance to air flow, spreading of the water and low entrainment.

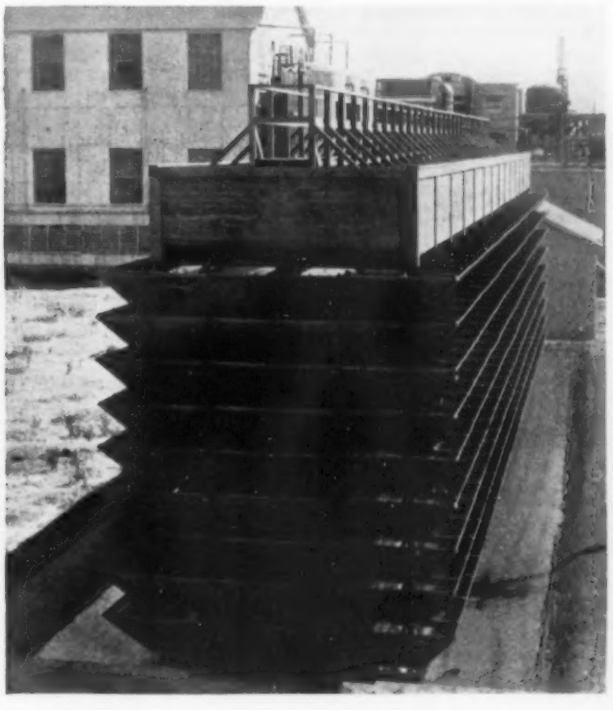
In this connection, a word might be said about the effective resistance of packed towers. It is known that resistance to the flow of a gas through a tortuous channel is due to two effects, the skin friction and the form drag. The former is the usual wall resistance encountered in flow through pipes while the latter is due to the inertial effects of change in direction and entrance and exit losses. From the analogy between momentum transfer across boundary layers and heat or mass transfer, it is probable that any increase in skin friction in a packed tower is accompanied by a proportional increase in the transfer coefficients. On the other hand, evidence indicates that the increase in the transfer coefficient accompanying an increase in resistance due to the shape of the surface is proportional only to the square root of the increase in resistance. The energy used in creating turbulence, therefore, is not as effective as that used to overcome skin friction. So far as humidification and dehumidification equipment is concerned, from the standpoint of power consumption, the ideal packing would consist of a bundle of vertical tubes, or a series of vertical plates. As a matter of fact, the latter forms the basis of one type of commercial contactor.[10] Since other factors besides power consumption usually enter into the choice of a suitable packing material, such as liquid hold-up, flooding velocity, permissible height, etc., it is usually advisable to include some inertial effects in order to decrease the size of the tower.

For dehumidification of gases by cooling, packed towers offer the advantage of permitting the cooling surfaces to be imbedded in the packing or actually serving as part of the contact surface. From this standpoint, dephlegmators consisting of vertical tubes, finned tubes and similar surfaces are actually wetted wall dehumidifiers. An interesting application of a combined humidifier, dehumidifier, and gas absorber of this type was recently proposed based on removing the heat of condensation by evaporative cooling.[4] The problem arises in absorbing a component of gas from hot gases having high humidity. In an ordinary absorption column the effluent temperature of an aqueous solvent would be very near the wet bulb temperature. The solubility of the component of the gas to be removed, however, in general

Unusual photograph of a B. F. Sturtevant Co. spray washer



Atmospheric water cooling tower of Foster Wheeler design



decreases rapidly with increase in temperature. Consequently, the rate of solution and the capacity of the solvent will often be very low due to the high wet-bulb temperature. A change of a few degrees in the temperature of the interface may mean the difference in the success or failure of the process. In such a case, rather than provide cooling coils and circulate enormous quantities of water, the interface may be cooled easily and cheaply by installing a series of vertical plates in the bottom of the absorption column. The walls of alternate channels are wet with water and cooled by evaporation into an air stream, while the opposite surfaces provide contact between gas and absorbent. A decrease of 15 deg. F. in the interface temperature has been found possible with such an arrangement.

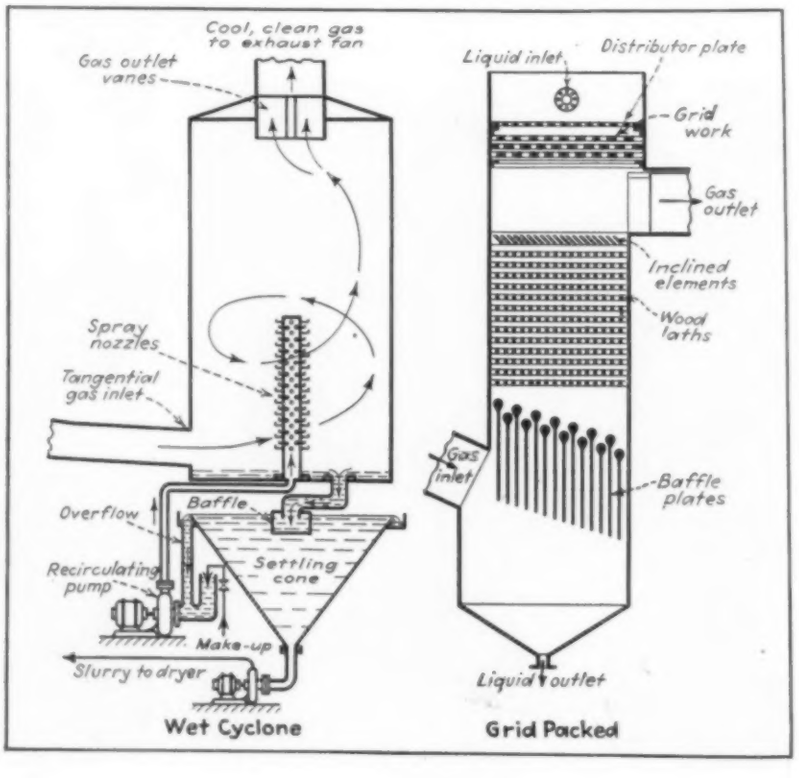
Devices for contacting gases with liquid by means of bubble surfaces are seldom used on a large scale for humidification, or dehumidification, probably because of the cost of construction and of moving the gas against the high resistance encountered. Aerators made of porous plates, or membranes, are commonly used in the laboratory for humidification. In industry, these are usually employed for the absorption of slightly soluble gases and evaporation of the solvent is only incidental to the absorption. From the fundamental theoretical aspects it would appear that the gas film resistance should control in humidification. The effective thickness of this film is undoubtedly greater in bubbles than in either of the other two types of surfaces. Consequently, aerators are not particularly efficient for humidification. This will be appreciated by anyone who has had the problem of saturating a gas by bubbling through a liquid. Bubble-cap plate columns might also be considered as primarily bubble surfaces. For gas conditioning equipment these are open to the same objection as bubble aerators.

So far in this paper only types of equipment have been considered. Numerous examples of each of these could be offered, each with certain unique fields of applications. The accompanying table illustrates how some of the equipment used in industry could be classified.

Summary of Equipment Which Is Used for Conditioning Gases

Type and Description	Uses	Advantages	Disadvantages
Spray, horizontal nozzles	Air conditioning by humidification, or dehumidification	Simple construction, low draft loss, baffles required contribute to efficiency	Large working volume, large ratio of liquid to gas
Spray, vertical nozzles	Same	Same	Same as above, uniformity of spray desirable, effectiveness decreases rapidly with distance in front of nozzle
Spray pond	Water cooling by humidification of air	Great simplicity, low first cost	Large loss by windage, power required for nozzles high, large ground area required
Spray, produced by mechanical action	Absorption, humidification, vapor recovery, dust and fume removal	Moderate draft loss, low liquid head, low liquid to gas ratio	Mechanical wear and corrosiveness of moving parts
Spray, from nozzles, propelled by cyclone action	Dust, mist and tar removal, absorption and humidification	Simplicity, no moving parts, low draft loss, high efficiency for humidification and gas absorption	Relatively large volume, large ratio of liquid to gas
Spray, formed by impingement and propelled by cyclone action	Same as above	No moving parts or nozzles	Higher draft loss than above
Packed tower, ceramic ware, coke, and crushed stone packing	Absorption and vapor recovery, humidification	High volume efficiency, moderate first cost, low liquid to gas ratio, large hold up permits saturation of solvent with gas	High draft loss, relatively low gas rates
Packed tower, grid packing	Absorption and vapor recovery, water cooling and humidification dust removal	High volume efficiency, low first cost — low draft loss, high gas rates	Low liquid hold up undesirable for some purposes, relatively high liquid to gas ratio
Packed tower, plate contactor	Absorption and vapor recovery, humidification	Low first cost, low draft loss, high gas rates, evaporative cooling possible	Low volume efficiency
Bubble, aerators	Humidification, absorption of slightly soluble gases	Low first cost, low liquid to gas ratio can be obtained	High power requirements, low gas rates, low efficiency for humidification
Bubble, plate columns	Absorption, vapor recovery and distillation, humidification	Standard construction, low liquid to gas ratio, high efficiency for distillation	Large draft loss, low gas rates, large hold-up, high costs, moderate to low efficiency for absorption and humidification

High absorption and humidification coefficients are attained with the Peaso Anthony scrubber (left) and the Nonhebel gas scrubber (used in England)



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Air Conditioning

By *EDITORIAL STAFF*. The principles of air conditioning have been covered in earlier articles, together with a general description of most of the fundamental systems and types of equipment. It remains to show how these principles and types of equipment are tied together into an operating whole for the purpose of controlling conditions of air. The article indicates the chief factors and how they are determined.

AIR CONDITIONING is generally divided into two principal types, comfort and industrial. Comfort conditioning requires controlling the conditions of air for the maximum practically attainable comfort of people within the conditioned space, whereas industrial conditioning is designed to give the optimum conditions of the air in relation to their effect on the properties of materials handled, processed or stored within the conditioned space. It may happen that optimum *industrial* conditions also correspond closely with optimum *comfort* conditions in a given case, but this is not necessarily true. Sometimes industrial conditioning must be a compromise between optimum processing conditions and optimum comfort conditions.

Complete Air Conditioning — The phrase "air conditioning" contemplates the simultaneous control of several of the most obvious properties of air, including (1) temperature, (2) humidity, (3) composition and purity, and (4) direction and motion. Anything less than the control of these four factors is not air conditioning, although some simpler process might accurately be described as partial air conditioning. At the present stage, the control of other factors such as the state of ionization of the air is not attempted.

Criteria of Comfort Conditioning— The process of dissipating body heat is not alone the transfer of *sensible* heat to the surroundings, but also involves the transfer of *latent* heat in the form of perspiration evaporated from the surface of the body. Therefore air conditions inhibiting the evolution of latent heat must be offset by ability of the air to remove sensible heat if more or less serious upsets in the body's heat balance are not to occur. With air of lower relative humidity or a higher velocity of flow over the body at the same temperature, more of the heat given off by the body can be in the latent form from which it follows that there are various conditions of air temperature, relative humidity and velocity which will permit the same rate of body heat evolution, and hence will give the same effect of air temperature. Many experiments of the American Society of Heating and Ventilating Engineers, and others, have established this fact and the society has plotted the various combinations of temperature and relative humidity which give the same effect of temperature (effective temperature). A simplified form of the A.S.H.V.E. comfort chart for still air

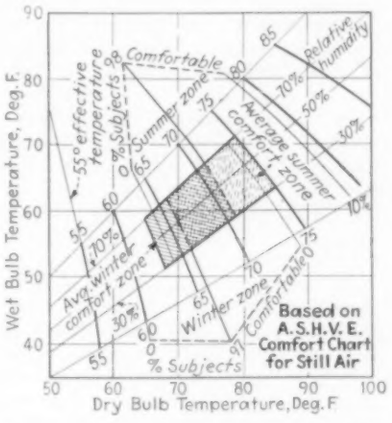


Fig. 1—Skeleton comfort chart indicating optimum comfort conditions in still air

(15 to 25 ft. per minute) appears in Fig. 1, from which it will be noted that the optimum effective temperatures vary from summer to winter. It is also to be noted that acclimatization is a factor in comfort and that this chart, developed for the northeastern part of the United States, does not necessarily apply in other regions. Nor does this chart apply at higher air velocities. The effect of more rapid circulation in increasing evaporation from the body is reflected in effective temperature lines for the higher velocities being displaced to the right on Fig. 1.

Changes in environment also have an effect on comfort, a fact which is evident from the feeling of shock which may follow changing from a high outdoor dry bulb to a conditioned space. For this reason for spaces in which the occupancy is of short duration it is customary to carry a higher effective temperature as the outside dry bulb increases. This question is covered in detail for various types of occupancy in the A.S.H.V.E. Guide and in books on air conditioning.

Criteria of Industrial Conditioning —As has been pointed out by L. Logan Lewis and others, industrial air conditioning has four principal aims, including the control of (1) physical properties of materials, (2) chemical reactions, (3) biological processes, and (4) comfort, health and efficiency of workers.

In the first classification are found such applications of air conditioning as in rayon (and other textile fiber) manufacture and handling; in tobacco processing; in the drying of numerous materials such as ceramics; and in the handling and packaging of numerous hygroscopic salts such as pharmaceutical preparations. Chemical control, as in the second classification, occurs in the drying of blast furnace air; and in the reactions employed in the production of viscose. Biological control, the third classification, has applications where fermentation reactions are employed as in brewing; in the production of bread and pastry doughs; preserving foods; experimental work on pest control, plant life, mold growth, etc. An outstanding example of the fourth classification, air conditioning for increasing the efficiency of workers, is found in deep mines where temperatures and humidities may be so high as to make efficient work impossible without dehumidification and cooling.

Air Conditioning Demands

NOW that it is clear that the conditions of air to be maintained in a conditioned space must be determined from the requirements of the space, whether they be for comfort or industrial needs, it is no longer necessary in considering how air conditioning can be accomplished to distinguish between comfort and industrial conditioning. Rather, it is necessary only to decide what the desired conditions are, what upsetting influences there are, and how these influences can be offset.

As has been explained air conditioning requires the simultaneous control of temperature, humidity and purity of the air, as well as direction and motion of the air flow. The upsetting factors related with each of these conditions of air may be listed as follows:

1. *Temperature*—(*a*) Transfer of heat from or to the surroundings by in- or exfiltration, conduction through the walls, doors or windows, or by radiation. (*b*) Release of sensible heat within the conditioned space by expenditure of electrical energy (motors, lights, heaters); by people or animals; by flames or other chemical reactions. (*c*) Loss of heat in combustion air supplied to furnaces discharging to the atmosphere.

2. *Humidity*—(*a*) Transfer of moisture in air from or to the surroundings by in- or exfiltration; or by actual passage through the walls owing to a difference in the partial pressure of water vapor between the conditioned space and its surroundings. (*b*) Release of moisture by vaporization processes or by combustion processes

Articles which appear in the earlier pages of this report have discussed the fundamentals of gas-vapor relations and the processes and equipment used in psychrometric operations. The remaining articles, of which this is the first, "button up" the preceding sections and show how air conditioning, solvent recovery and air drying employ the principles enumerated.

discharging flue gases into the conditioned space; and moisture evaporated by people and animals. (*c*) Loss of moisture by condensation on cold surfaces such as walls, roofs or windowpanes.

Composition and Purity—(a) Entrance of dust, dirt, bacteria and pollen into the conditioned space by infiltration or other means. (*b*) Production of dirt, fumes, gases or odors within the conditioned space by manufacturing processes, reactions or combustion. (*c*) Discharge of body odors and bacteria into the conditioned space by people or animals.

Direction and Motion—Left to itself, the convection of air within the conditioned space may not be sufficient to produce the desired rate of body evaporation. Natural convection and in- and exfiltration may not produce adequate ventilation. On the other hand, air conditioning requires movement of considerable quantities of air from the conditioned space to the conditioning equipment, and between the space and the outside for ventilation. The control of direction and motion therefore requires proper design of the distribution system to the end that air motion in the conditioned space be reasonably uniform and preferably imperceptible.

Determining Gains and Losses

From the above outline, it is clear that the principal gains and losses to be considered in an air conditioning installation are those of heat and moisture. Control of air purity is generally relatively simple and will therefore be considered first.

Air Purity—For ordinary air conditioning purposes, the capacity of a device for maintaining air purity is determined not by the amount of material to be removed from the air, but by the amount of fresh air and recirculated air to be handled by the system. Therefore the question of determining the amount of such impurities is ordinarily not considered.

Although it is true that people within the conditioned space consume oxygen and give off carbon dioxide, it has been demonstrated that the vitiation of air does not depend in any way on the minute changes of concentration of these substances that can occur even under conditions of excessive crowding. Rather, air vitiation arises from body odors and the increase in humidity and temperature due to occupancy. Odor control is generally accomplished by dilution, i.e., by providing a certain proportion of fresh outside air, the proportion as shown by books on air conditioning depending on the number of occupants and the kind of activity within the conditioned space. In conditioned spaces where chemical reactions are not carried out, odors are generally organic in character and the odorous ingredients present in immeasurably small concentrations. Some reduction in the odor concentration of air can be made by air washing, while a greater reduction is possible by passing the air over activated carbon which, when it is of a suitable type, can adsorb up to 20 per cent of its weight in odor producing materials. Thus installations employing either air washers or activated carbon adsorbers, can dispense with a part or even all of the intentional ventilation which would otherwise be required, thus reducing considerably the quantity of outside air that must be conditioned.

Humidity and temperature increase, the other factors in air vitiation, will be covered later. At this point, therefore, the remaining factor in air purity, that of foreign bodies such as dirt, dust, bacteria and pollen in the air, will be considered. In general, three methods are used to remove foreign bodies: (1) filters, (2) air washers, and (3) electrostatic precipitators.

1. The most common method is to employ filters, which are either of the throw-away or of the cleanable type. Among throw-away filters, both cloth and paper filter media have been used to a considerable extent, but the present trend seems to be toward fiber glass filters, the fibers of which are given a viscous coating to entrap particles in the air. There are some large installations using throw-away filters but more commonly where the air throughput is considerable, cleanable filters, especially automatically cleaned filters of the curtain type, are used.

2. Probably the greatest number of large air conditioning installations employ a spray washer for humidity control, and since a spray washer is an effective air cleaning device, it dispenses with filters.

3. A recent development is the Precipitron type of electrostatic precipitator which is employed principally for air cleaning. Current supply is taken from an ordinary power circuit and converted by means of vacuum tubes. Such units are simple and are claimed to require little maintenance, yet have a high cleaning efficiency for solid particles in air.

A recent development is a combination self-cleaning filter and electrostatic precipitator designed to separate the larger air-borne particles by filtering action, and the finer particles down to the size of smoke by electrostatic action.

Sensible Heat Gains and Losses—The first requirement in calculating any air conditioning system is to determine the quantity of heat that must be released in or removed from the conditioned space per unit of time. Ordinarily, when the heating and cooling of air and its contained water vapor are mentioned, sensible heating or cooling is meant, which is the change in heat content which brings about temperature change. Moreover, when the process involves changes in moisture content as well as temperature, it is shown in Fig. 2 that a change in the latent heat of the moisture in the air also takes place and that the entire change can most conveniently be considered a change in the total heat of the air.

Determination of the sensible heat gains or losses in the conditioned space requires first setting up the

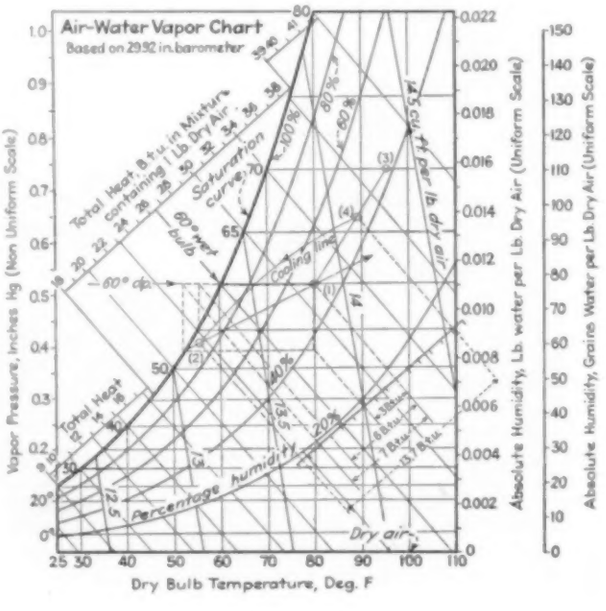

Air-Water Vapor Chart
Based on 29.92 in. barometer
Vapor Pressure, Inches Hg (Non Uniform Scale)
Absolute Humidity, Lb. water per Lb. Dry Air (Uniform Scale)
Absolute Humidity, Grains Water per Lb. Dry Air (Uniform Scale)
Dry Bulb Temperature, Deg. F
Total Heat, B.t.u. in Mixture containing 1 Lb Dry Air
Saturation curve
60° wet bulb
60° dp
Cooling line
Total Heat
Percentage humidity
Dry air
13.5 cu. ft. per lb. dry air

Fig. 2—Solution of typical air conditioning problem

Problem: Air to be maintained at condition (1) by coil cooling and condensation. Space conditioned has 7,000 B.t.u. per hour sensible and 3,000 B.t.u. per hour latent heat gain. 150 c.f.m. of fresh air at condition (3) is to be supplied. Find refrigeration required.

Solution: Lay off convenient auxiliary total heat scale at lower right. Since gain is 7 B.t.u. sensible to 3 B.t.u. latent, project 7 B.t.u. on dewpoint line through (1) and project 3 B.t.u. on dry bulb line through (1). Complete parallelogram and draw diagonal (1)-(2) for direction designating proportion of sensible to latent gain.

Coil produces 90 per cent of saturation in air, determining point (2). Project sensible heat gain (1)-(2) on total heat scale = 6 B.t.u. per lb. sensible gain from coil to room condition, requiring 7,000/6 = 1,167 lb. cooled air per hour, which at 13.16 cu. ft. per lb. = 15,320 cu. ft. per hour. 9,000 cu. ft. per hour fresh air ÷ 15,320 = 58.6 per cent fresh air, determining by proportion point (4) on line (1)-(3), thus giving condition of mixture to coil. Project points (4) and (2) on total heat scale = 13.7 B.t.u. per lb. cooling in going from (4) to (2). Therefore, 15,320 x 15.7 ÷ 13.16 = 15,900 B.t.u. per hour cooling load = 15,900 ÷ 12,000 = 1.325 tons refrigeration.

Products and Industries in Which Air Conditioning Can Be Used Effectively

Based upon a list drawn up for *Chem. & Met.* by the Carrier Corp., plus a survey of the literature and known applications. Not all the applications are for complete air conditioning but applications where only refrigeration is required have not been included. The list is presented in the hope that it may prove suggestive of applications where air conditioning principles could be used to advantage but are not now being used.

Control of Physical Properties

Manufacturing and Processing—Abrasive wheels, sand paper; adhesives; artificial leather; asphalt base floor coverings and roofings; baking powders; blast furnace air; blueing; candles; cellulose sheeting; ceramics; chemicals, miscl.; cigarettes and cigars; cork products; cotton spinning; decals; drug grinding and preparations; engraving; explosives; films; glass (precision grinding), and safety glass; glue and gelatine; gypsum curing; leather; linoleum; lithography and printing; matches; medicinals and pharmaceuticals; nylon; paper, including photographic; paper boxes; refrigerator cabinets; rubber; sausage casings; soap; sugar; synthetic fibers; synthetic rubbers; textiles.

Foods—Bread and bakery products; candy; cereals; cheese; chewing gum; coco butter; coffee; frozen foods; macaroni; malt; sausages; sugar; starch; yeast.

Precision Products—Cylinder blocks; engravings; multi-color printing; optical instruments; precision machine work; watches; telescope lenses.

Testing and Research—Animal experiment rooms; medical and research laboratories; cellulose research including sheeting and rayon; paint; paper; textiles.

Storage—Books and documents; explosives; films; food; furs; grain; matches; paper; precision tools and instruments; sugar.

Control of Chemical and Biological Reactions, Health and Efficiency

Rayon, blast furnaces, explosives, linoleum, plastics, synthetic yarns. Breweries, cheese, meat packing, milk products, pharmaceuticals, ripening fruits, yeast. Efficiency control, deep mines, and other hot workings.

design conditions, which are the most severe conditions likely to be encountered *on the average*. From the study of weather bureau records, books on air conditioning give tables from which suitable design conditions can be determined. For a space which is to be conditioned both summer and winter, it is necessary to make separate calculations for the winter heating load and the summer cooling load, in each case choosing suitable indoor conditions which are to be maintained in the face of the worst probable (design) conditions out of doors.

Heating Load—Heat losses for a conditioned space are calculated for the assumed temperature difference between the conditioned space and the outside, determined as the losses through each wall, the floor and the roof, in terms of the heat transfer co-efficient for the various materials used in the construction of the space, and the area of each material. Books on air conditioning give extensive tables of heat transmission co-efficients for various sorts of building construction. To the transmission loss must be added the loss due to air leakage and the air taken in in controlled amount for ventilation.

Offsetting the required heating load, of course, will be all sources of heat within the building, including that from the heating equipment. Deducting from the sum of the losses (i.e., the transmission plus infiltration plus ventilation loads) the sum of the gains (i.e., heat equivalent of all electric power used in the conditioned space, plus incidental heat such as gas flames, plus an estimate of the sensible heat given off by the occupants of the space) leaves the net heat loss which must be made up by the heating equipment. Where large numbers of people are congregated, a considerable part of the heating load may be supplied by the emission of "animal heat," with a quantity varying from 225 to about 600 B.t.u. per hour per person, depending upon the state of activity.

Actually, however, for conservative rating of the required heating equipment, credit is usually not taken for auxiliary heat sources such as those mentioned above.

Cooling Load—Determination of the summer cooling load is similar to the calculation of heating load except that several additional factors are encountered. Auxiliary heat sources such as heat given off by people become more important in cooling calculations (since they *increase* the size of cooling equipment required, whereas they *reduce* the size of heating *load* but not the size of the heating equipment). Also solar radiation is taken into consideration. The normal transmission gain alone will give a result much too low. Solar heat gain is difficult to determine accurately owing to its periodic character and to the fact that various transmitting elements of the structure lie at different angles to the radiation (while these angles change with the motion of the sun). Furthermore, various finishes reflect a greater or lesser part of the radiation which hence cannot be transmitted. Tables in the literature give the actual intensity of solar radiation falling in an hour on a square foot of surface of various orientations at various times of the day and at various latitudes. A percentage of the total radiation is calculated by applying a factor depending on the normal transmission coefficient of the surface, modified by another factor depending on the reflecting character of the surface. These tables also give the actual transmission through glass of various orientations. There may be considerable lag in solar transmission, owing to the type and thickness of the wall or roof.

Latent Heat Gains and Losses

Vaporization of moisture into a conditioned space results in an increase in the latent heat of the air, or more accurately, in the latent heat in moisture associated with the air. Commonly, winter conditioning requires the vaporization of additional moisture to increase the humidity of the air, while summer conditioning requires the condensation of moisture to reduce its humidity. Although the latent heat of steam at the low partial pressures at which it is present in air is actually variable, nevertheless for ordinary calculations, it may be stated that 1,050 B.t.u. of heat must be supplied to the water from the air or by direct heating in the vaporizing of each pound of water, while a similar amount of heat must be withdrawn from the moisture in the air to affect the condensation of a pound of moisture.

The problem of humidification is considerably easier to solve than the converse question of dehumidification since steam, the latent heat of which can be supplied in any suitable manner, can be released directly into the air, or the air can be passed over the surface of heated water or through heated water sprays.

Dehumidification, however, requires the separation of the moisture from the air by condensation either by lowering the temperature of the air-vapor mixture enough to condense the required amount of water; or by condensation at the air temperature by adsorption or absorption of the moisture. However, in any event, latent heat gains and losses can be treated similarly in air conditioning calculations to sensible heat changes, and in fact, where both types of heat change, calculations are made on the basis of the difference of total heat before and after the change.

Latent Heat Losses—Winter air is normally at a fairly high percentage humidity, but being cold, its absolute humidity (pounds of water per pound of dry air) is low. Hence, when humidification is practiced, normal infiltration losses will result in a continuous loss of moisture from the conditioned space, in addition to losses that may take place by reason of condensation on windows or other insufficiently insulated surfaces; and by passage of moisture through the walls owing to the partial pressure difference between the conditioned interior and the unconditioned exterior. Indeed, this latter effect may result in damage due to condensation within the walls if the wall air spaces are not sufficiently well ventilated, and if the inner wall surfaces present too little resistance to moisture passage.

Latent Heat Gains—Offsetting latent heat losses in winter is generally a relatively small part of the total heat load required. In summer, however, a considerable part of the cooling load may be in the form of latent heat. In the majority of cases the principal latent heat gain will be from the outside air, both from infiltration and from ventilation. Where in winter the absolute humidity of outside air tends to be low, in the summer the reverse is generally true. Where in winter the re-

sult of heating of outside air is often a relative humidity of Sahara Desert dryness, in summer the cooling of outside air may bring about a condition close to saturation unless dehumidification is practiced in addition to cooling. Furthermore, except when they are at rest, people give off more latent than sensible heat, the quantity increasing rapidly as the degree of exertion increases, ranging from about 160 to more than 1,200 B.t.u. per hour latent heat. Finally, other processes such as the discharge of combustion flue gases into the conditioned space, or a chemical reaction, may also increase the latent load.

Air Conditioning Cycles

EARLIER articles have discussed the properties of air-moisture mixtures, described various types of psychrometric chart, and shown the various operations and equipment that may be used in bringing about the heating or cooling, humidification or dehumidification, of air or other gases. At this point it may be worthwhile briefly to review the principal cycles that may be employed.

Unit and Central Systems—Two general methods of air conditioning are used: the unit system and the central system. The former employs as many small complete air conditioners as may be needed, placed strategically at various points in the conditioned space; and the latter, a single large air conditioner which is piped by ducts to numerous points throughout the conditioned space so as to give as uniform distribution of the conditioned air as possible. Some of the equipment of a unit system may, however, be central. For example, all of the unit conditioners may be piped to a common cold water supply and a common steam supply.

Heating—In air conditioning the heating of the conditioned space is applied either by direct radiation in the conditioned space, as a supplement to the air conditioning equipment, or by radiation applied to the circulating air in the conditioning equipment. Use of direct radiation alone can control only temperature and hence is not complete air conditioning. Except for small domestic air conditioners, heat is nearly always supplied through the medium of steam which heats the air as it passes over an extended surface coil.

Humidifying—In small air conditioning systems water may be evaporated into the air by passing the air over pans of heated water or over wicks suspended in water. Occasionally steam is blown directly into the atmosphere. In larger systems having complete air conditioning, the air passing through the conditioner is sprayed with water in the conditioner (or with the solution used for dehumidifying in installations employing chemical absorption in the summer). Where humidification is practiced industrially without a complete air conditioning system, several types of unit humidifiers are available. Sometimes steam is blown directly into the atmosphere but more frequently warm water is finely dispersed into the atmosphere either by sprays or by a mechanical device capable of producing extremely fine atomization.

Cooling and Dehumidification—Whereas heating and dehumidification may be either coincident or separate functions, when cooling is employed it is usually combined with dehumidification, since cooling alone would result in increasing the relative humidity of the air and contributing to discomfort. Two general types of processes are available for dehumidifying: (1) refrigeration and (2) absorption with liquids and solutions of low vapor pressure and adsorption with materials such as silica gel and activated alumina. With refrigeration, air is cooled below its dewpoint, causing condensation, and further cooled with continuing condensation until some satisfactory lower dewpoint is reached. At this lower dewpoint, the air will be close to saturation and must usually be reheated to a usable temperature. With ad- and absorption, however, air could theoretically be dehydrated at constant temperature provided that the heat of ad- or absorption were removed as fast as released. Actually in such cycles, the cooling required for removal of the heat released cannot be applied in this way but the eventual effect on the air is the same when cooling takes place after ad- or absorption. Generally with such processes further cooling is practiced so that the final air not only has a lower dewpoint (humidity) but also a lower dry bulb temperature than the initial air.

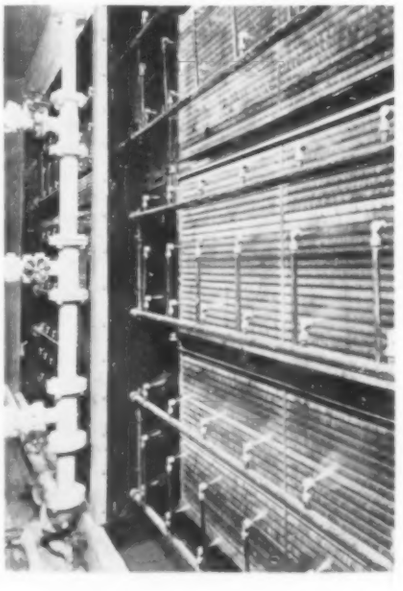
Refrigeration Methods—Air can be cooled and dehumidified with natural cold water, with ice, and with mechanical refrigeration. If the relative humidity is low, air may also be cooled and *humidified* by adiabatic evaporation of water into the air stream. Natural cold water is rarely available in the summertime at temperatures low enough to accomplish much dehumidification, unless from deep wells. Where cold well water is to be had, no cheaper method of dehumidification can be practiced, but where the air conditioning installation must bear the cost of drilling the well, other dehumidification processes will generally be preferable. Water from wells 30 to 60 ft. deep in the North Atlantic states will be in the range of 42 to 52 deg. F. and hence capable of maintaining dewpoints from 47 to 57 deg., or well within the summer comfort range. In the Southern states, however, water from such wells ranges 62 deg. and higher and hence is of questionable value as a dehumidifying agent.

Ice is used to a considerable extent for dehumidifying and cooling railroad cars, but not much for other air conditioning purposes. An installation using ice has the advantage of low first cost against which must be offset higher operating costs than for mechanical refrigeration. For an installation having a low annual use factor, ice may be advantageous in that it forces the ice manufacturer to carry the principal part of an investment which otherwise would impose an undue depreciation cost per hour of use. The air to be conditioned may be blown across ice cakes in a bunker and through a spray of the melted ice water, or the ice may be used to cool recirculated water for an ordinary spray washer.

Mechanical refrigeration is the principal method of cooling and dehumidification now in use. Two general methods: cooling with coils and with cold water and spray washers are used. Absorption refrigeration is being used to a small extent for this purpose, principally where exhaust steam is available. Much more common are installations employing reciprocating or centrifugal compressors, or steam jet water coolers. Some use, at present is also being made of certain types of rotary compressors.

Reciprocating compressors generally employ methyl chloride, sulphur dioxide, ammonia or one of the fluorochloro-methanes such as F12 and F11 as a refrigerant; while with the centrifugal compressors, methylene chloride, monochlorotrifluoromethane or water vapor are used. Refrigeration is conveyed to the air or to the cold spray water, either by direct expansion of the refrigerant in the cooling coils, or by a cold carrier liquid such as brine or water which is passed through the air cooling coil. Except in small

Carrier spray-coil dehumidifier in new Church & Dwight plant at Syracuse, built by the Austin Co.



unit room conditioners the refrigerant condenser is nearly always water cooled. An important trend whereby the use of condenser cooling water is reduced to only about 5 per cent of that otherwise required is the increasing application of recirculated condenser water cooled adiabatically in a cooling tower or evaporative condenser. Small room units with air-cooled condensers frequently gain added cooling effect by spraying the condensed water taken from the air on to the condenser coils.

When refrigeration is used for dehumidification, the air leaving the coil or spray washer will be close to saturation—perhaps 90 per cent relative humidity with a coil or 95-98 per cent relative humidity with a washer. Therefore, even though it may be mixed with bypassed return air, it will rarely be fit to use in the conditioned space without reheating, for otherwise too low a temperature would be maintained. Actually, since relatively little heat is needed for sensible heating, this apparently wasteful process is not particularly onerous, although reheating can be avoided with ad- or absorption dehydration.

Dehydration Methods—Use of solid adsorbents and liquid absorbents is being practiced to an increasing extent for dehydration of air. The term dehydration is generally employed for such processes to distinguish them from refrigeration dehumidification. The solid adsorbents, silica gel and activated alumina, have the advantage of being able to produce extremely low dewpoints. The liquid absorbents, however, are more readily handled in that they can be pumped over the contacting and regenerating equipment. Lithium and calcium chlorides and various mixtures of salts in water solution are the materials chiefly employed. Anhydrous soluble calcium sulphate is also used to some extent.

Air Conditioning Calculations—Although calculations relating to the properties of air and water vapor mixtures can be made with nothing more than first principles and the steam tables, the use of a psychrometric chart greatly facilitates the solution of the problem not only because it permits visualizing the required cycle, but also because to a considerable extent it substitutes graphical for calculation methods. This is particularly true of some of the modern charts especially designed for graphical use. One point should be emphasized, however, and that is that the chart user should, before attempting to employ the chart, make an effort to understand thoroughly how it is constructed and what approximations were used by the chart maker. Also, he should learn the actual meaning of the various lines and scales and how different cycles are traced on the chart. Otherwise he is in danger of falling into the calculation-by-rote methods which seem to be advocated by some writers.

Recovery of Solvent Vapors

By *ARTHUR B. RAY*, of Carbide and Carbon Chemicals Corp., New York, N. Y.

As it is essentially a problem in separation of vapor mixtures, solvent recovery can be accomplished by several different methods: by condensation on cooling, by absorption in liquids and by adsorption with activated carbon.

AMERICAN INDUSTRIES use tremendous quantities of low-boiling organic liquids—generally spoken of as "solvents"—in carrying out various manufacturing operations. In many cases, these solvents act merely as dissolving or carrying media for materials such as nitro-cellulose, cellulose acetate, synthetic resins, plastics, and rubber products, and are vaporized into the air during the manufacturing process. In some cases solvents are used to extract oils from materials such as soya bean meal. Efficient recovery makes it possible to eliminate solvent cost as a first consideration and makes it unnecessary to use a cheap solvent if a higher priced solvent will improve the quality of the manufactured product.

Since in most cases the solvents are vaporized in manufacturing operations exposed to air, the recovery must be made from vapor-air mixtures. And since most of the commonly used solvents are flammable when their vapors are mixed with the proper amount of air, vapor concentration is particularly important from the safety standpoint. Data regarding reported limits of flammability of the common solvent vapors in air are given in *Chem. & Met.*, Jan. 1940, p. 31, Factory Mutual Data Sheet No. 36.10, Jan. 1940, and U. S. Bureau of Mines Bulletin No. 279.

If the concentration of a vapor in air is kept below the lower limit of flammability the mixture cannot be ignited or exploded under normal conditions of temperature and pressure and the recovery of vapors under these conditions presents no hazards. Likewise, if the concentration of vapor is kept above the upper limit of flammability the mixture is not flammable or explosive, but in working with these concentrated mixtures there is always the possibility that the concentration may get into the explosive range by dilution with air leaking into the system or by failure to vaporize solvent at the required rate to maintain the high concentration. It is generally considered that manufacturing operations and recovery processes which require vapor concentrations in air above the upper limit of flammability are hazardous and are to be avoided if possible. Where high solvent vapor concentrations are necessary to carry out a process, it is advisable to employ an inert atmosphere or a non-flammable solvent to avoid hazards.

From the above discussion, it is evident that in evaluating any method of solvent recovery one must first consider if its characteristics will permit safe operation. Other important criteria by which a recovery process must be evaluated are: recovery efficiency, recovery expense, flexibility to meet varied operating conditions, and relation between initial cost and savings.

Since it is impossible in this brief article to discuss all the possible recovery methods or, in fact, any one method in detail we shall limit our discussion to recovery by condensation, absorption with liquid media, and adsorption with activated carbon.

Recovery by Condensation — Solvent vapors can be recovered by condensation when the vapor-gas mixture is cooled below the dewpoint. The solvents are usually vaporized at an elevated temperature and the vapor-air mixture is cooled by bringing it in indirect or direct contact with cooling media such as water or refrigerated solutions. When the cooling medium is water, the temperature cannot ordinarily be reduced below 60 deg. F. The vapor pressure of practically all common solvents at this temperature is such that the minimum concentration of vapors is either in or above the explosive range. This means, of course, that such a condensation process of recovery must unavoidably handle vapor concentrations which are hazardous. If air is replaced by an inert atmosphere to avoid the hazard, the condensation process still has objections. Since the concentration cannot be reduced below a rather high value, the material being processed cannot be completely freed of the solvent, and the vapor-laden air must be recirculated to avoid large loss of solvent. Because of unavoidable solvent losses, such a system does not ordinarily recover more than 60 to 70 per cent of the solvent vaporized and usually the recovery is much less. Water vapor present may also be condensed and, if water soluble solvents are recovered by such a condensation method, the condensate must be distilled. It is evident that the recovery of solvents by condensation at temperatures which can be reached with ordinary cooling water has definite disadvantages. Possible favorable factors of the system are low operating expense and relatively low equipment cost. Because of the disadvantages of such a system, it is not widely used, having been largely replaced by the activated carbon system. There are, however, a few condensation systems of the type described in operation where it is advantageous to keep the processed material in a

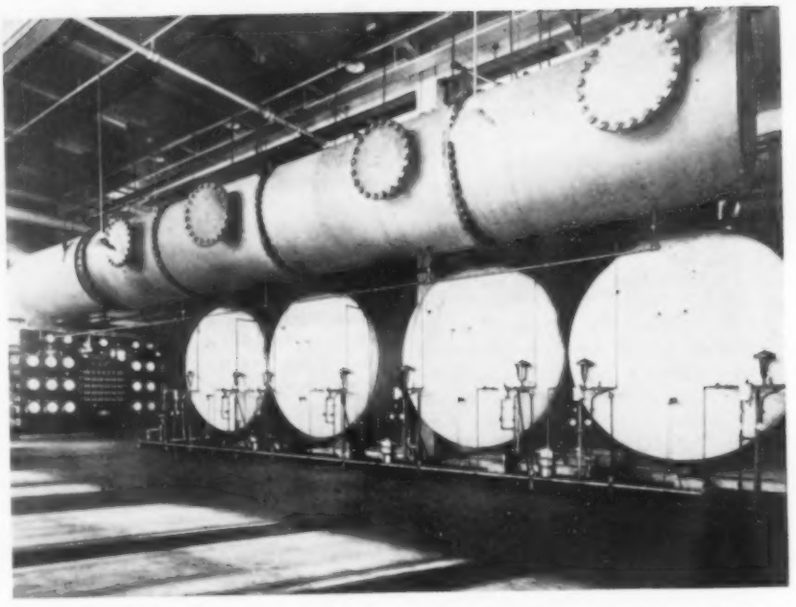
high concentration of the vapor of the solvent.

A type of condensation recovery system which cools the vapor-laden air to very low temperatures by means of mechanical refrigeration has been employed and at least one such system is still in operation in the United States for the recovery of acetone. In one such system, which has been replaced by a Columbia* activated carbon system, air at 95 deg. F. containing approximately two per cent acetone was cooled to —40 deg. F. to effect partial condensation and recovery of the acetone. The cooled air contained approximately 0.65 per cent acetone vapor and although the system was designed to recirculate all of this air there was unavoidable leakage. Advantages of the activated carbon system over this condensation system which it replaced are reported as: "Lower original cost, greater overall efficiency, lower recovery expense per unit of recovered solvent, somewhat less building space required and indicated low maintenance cost." It should be added that the activated carbon system has a larger factor of safety because it treats air containing a concentration of acetone well below the explosive range. It may also be pointed out that the activated carbon plant is much more flexible because it will recover solvents which can not be effectively recovered by the condensation system, and it will operate efficiently intermittently and under widely varying conditions of temperature, humidity and vapor concentration.

Solvents used to extract oil from soya bean meal and such materials are generally vaporized from the material by reducing the pressure and heating to a moderate temperature. The small amount of solvent carried out of the systems in the saturated air discharged from the vacuum pumps is generally recovered by means of activated carbon but the bulk of the solvent vaporized from the meal is recovered as is logical by merely condensing it in suitable equipment cooled by water at normal temperatures.

All the available information indicates that the condensation system of solvent recovery from air has many disadvantages and is fast disappearing since the development of better recovery systems.

Recovery by Absorption in Liquids—To recover solvent vapors by absorption in liquids it is necessary to pass the vapor-laden air in efficient contact with the absorbent under conditions which will permit the liquid, at a suitable temperature, to extract the vapor from the air more or less completely. Contact may be effected by the use of spray chambers or scrubbing towers. When water soluble solvents



Typical large automatic "Columbia" activated carbon vapor recovery system

are to be recovered by absorption, water is the usual absorbent, and when the absorption method is used to recover oil-soluble solvents, a mineral oil is the usual absorbent. Both of these absorbents hold solvent vapors in accordance with Henry's Law which states that a volatile substance dissolved in a liquid exerts a vapor pressure proportional to the amount of the substance present. This means, of course, that the amount of solvent vapor which the absorbent liquid will hold and the practical recovery efficiency of such an absorbent are dependent upon the concentration of vapor in the air passed to it. It also means that it is impractical to remove all of the vapor from the air by such absorbents. Some special liquid absorbents have been suggested and used which form readily decomposable compounds with certain solvents or by other means hold solvents in larger amounts than do water or mineral oil. Such special absorbents will not be discussed here because, to the best of the writer's knowledge, they are no longer used to any extent in the United States.

The method of recovering solvent vapors from air by absorption in a mineral oil having a high vapor pressure is of limited applicability and use. In general, it may be said that when the concentration of the vapor to be recovered is low enough to be safe, recovery by oil absorption is relatively inefficient and expensive. The oil absorption method is, of course, widely used to recover gasoline from natural gas and light oils from manufactured gas under favorable high pressure conditions and where the presence of impurities in the gas makes other methods impractical.

Before the development of the modern activated carbon system of solvent recovery, water absorption was the method most favored for the recovery of such widely used water soluble solvents as acetone and ethanol. When acetone is recovered by water, very cold well water or water cooled by refrigeration is generally used. Since the efficiency of recovery and concentration of acetone in the water leaving the scrubber are both effected by the vapor concentration and the temperature of the water, the vapor concentration is kept as high as possible and the temperature of the water as low as is practicable. For safety reasons, the vapor concentration is usually kept below the explosive range, but because the efficiency and expense of recovery are both favored by high vapor concentration, the possible factor of safety for absorption systems (as they are usually operated) is less than for the activated carbon system.

While the type of scrubber and recovery conditions may vary, it will be of interest to give available data regarding one large modern absorption plant. In this plant the vapor-laden air is passed to a multistage spray-washer type of scrubber in which the solvent-air mixture is passed through successive chambers into which water is sprayed, this water being pumped from one chamber to the next countercurrent to the flow of air. Concentration of acetone vapor in the inlet air may be as high as 1.75 per cent but occasionally is considerably lower. The air leaving the scrubber always contains some acetone vapor and under favorable conditions the concentration may be as low as 0.06 per cent. The plant is designed to recirculate the effluent air from the scrubber back to the process, but some leakage is unavoidable with consequent loss of acetone. The water entering the first scrubber is at a temperature of approximately 34 deg. F., and approximately 300 tons of refrigeration are

* "Columbia" is the registered trademark for activated carbon marketed by Carbide and Carbon Chemicals Corp. Activated carbon systems described here all employ this product.

required per ton of recovered solvent. The water-acetone solution leaving the scrubber contains approximately 2.6 per cent acetone by weight necessitating unusually large rectification equipment. It is reported that the overall recovery varies with the inlet vapor concentration and other conditions but may range between 92 and 95 per cent.

Since an activated carbon system is operated under the same conditions as the water absorption system just described, except that the vapor concentration with the carbon system is lower, it is of interest to compare the two. The carbon system requires no refrigeration and effects substantially complete recovery of the acetone from the air even though the vapor concentration, temperature and humidity of the inlet air vary considerably. The acetone-water solution steamed out of the carbon contains 20 to 33 per cent acetone by weight. The overall recovery by the carbon system is reported to be 98.5 to over 99 per cent. Reported comparative data regarding utility requirements of the two systems are given in the accompanying table.

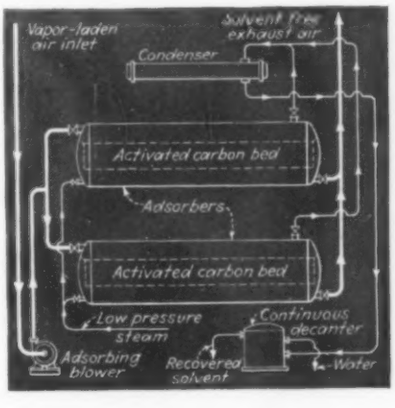
	Per 1,000 Lb. of Recovered Acetone	
	Water Absorption	Activated Carbon
Steam at 415 lb. per sq. in. and 150 deg. F. superheat	5,520 lb.	None
Steam at 15 lb. per sq. in.	4,040 lb.	3,960 lb.
Water at 55 deg. F.	17,445 gal.	8,750 gal.
Electric power	251 Kw.-hr.	82 Kw.-hr.

Because of the demonstrated advantages of the activated carbon system it has superseded the water absorption system in a number of large plants where the old system has been used for many years. It is probable, however, that in some cases the water scrubbing system may be continued in use where operating conditions particularly favor it.

Recovery by Activated Carbon—The most generally used method of recovering all types of solvents at the present time is by adsorption with activated carbon. This solid adsorbent, when of the proper type, is especially made for efficient and low cost recovery of solvent vapors under widely varying conditions. The carbon adsorbs substantially all the vapor from the air regardless of variation in concentration, temperature and humidity conditions. Because the adsorbed solvent has practically no vapor pressure at normal temperatures, the carbon system is particularly adapted for the efficient recovery of solvents present in air in low concentration. This means that carbon recovery systems can always be designed for operation without hazard because the vapor concentrations are always below the flammable range. The type of activated carbon generally used in the United States has a high specific adsorptive power for organic vapors and therefore recovers such vapors efficiently when water is present in the air or in the carbon. Since activated carbon adsorbs all the usual low boiling solvent vapors, it can be used to recover practically any single solvent or any combination of low-boiling solvents vaporized in manufacturing operations.

In order that the adsorptive properties of activated carbon may be utilized to effect recovery of solvent vapors, special equipment and operating procedures have been developed. An understanding of the adsorption recovery process may be obtained by an inspection of the flow chart shown in Fig. 1 which shows how one type of activated carbon system operates. The filtered and cooled vapor-laden air is drawn under automatically controlled conditions from the solvent-vaporizing operation and is passed to the bed of activated carbon in one of the adsorbers. The activated carbon adsorbs and holds the solvent vapor and denuded air is discharged to the atmosphere. The passage of vapor-laden air is continued until the activated carbon bed has adsorbed the desired quantity of solvent. If the vapor is passed to the carbon bed at a constant rate, the desired charge is obtained by keeping the adsorber in service for a definite period. If, however, as is most often the case, the vapor is passed to the adsorber at a widely varying rate, an especially sensitive vapor detector in the air exhausted from a portion of the carbon bed indicates when the bed is charged to the proper limit. When the carbon bed in one adsorber is charged with vapor, the vapor-laden air stream is either manually or automatically switched to the other adsorber. The adsorbed solvent is then driven out of the charged adsorber by introducing low-pressure steam at a controlled rate below the carbon bed. The steaming is continued for about 15 to 60 minutes and then the adsorber is ready to be placed in service again. The steam passing through the charged carbon causes the release of the adsorbed solvent vapor and the steam-solvent vapor mixture discharged from the adsorber is condensed. If the solvent is not appreciably soluble in water it is separated from the water by an automatic continuous decanter. If the solvent is completely soluble in water it is separated by distillation.

Fig. 1—Flow diagram showing operation of an activated carbon adsorption system



While many recovery plants are of the type just described, other activated carbon plants for the most efficient recovery of valuable solvents are operated so as to include a period after the steaming operation in which the carbon is partially dried and cooled. Various modified operating procedures may be employed to obtain most efficient recovery under special conditions. Some plants which are not required to operate continuously contain only one adsorber which is charged during several hours operation and is then steamed and cooled and returned to service when required. Many large plants contain a number of adsorbers which are operated in parallel to give the desired air handling and solvent recovery capacity. The type and amount of solvent, the volume of vapor-laden air and other conditions determine the number of adsorbers and the operating procedure which is needed.

While the activated carbon method of solvent recovery is used in practically all solvent-using industries some of the largest activated carbon plants are in industries which manufacture rayon, transparent wrapping and lacquer-coated or impregnated fabrics. A view of a typical large plant is shown by the opposite page. This plant is now being expanded by the addition of four more adsorbers.

Recovery of solvents by adsorption is accomplished at low cost as the following information regarding recovery by an activated carbon system shows. The steam requirement ranges from less than 3 lb. to about 5 lb. per pound of solvent recovered. The high steam consumption is required when the recovered solvent must be redistilled to make it suitable for reuse. The consumption of electric power varies with the concentration of the vapor in the air. In typical recovery plants where the concentration of the solvent vapor is 40 to 50 per cent of the concentration at the lower limit of the explosive range, the power consumption is approximately 0.04 to 0.08 kw.-hr. per pound of solvent recovered. For recovery of a solvent such as benzol, the requirement of water at a maximum temperature of 70 deg. F. is approximately 7 gal. per pound of solvent recovered. For the recovery and redistillation of a solvent such as acetone, the requirement of water at 70 deg. F. is approximately 9½ gal. per pound of solvent. The operation of the recovery plant is simple and even when the operations are manually performed one operator is all that is required for even a large recovery plant. Where the operation of the recovery plant is automatic no regular operator is required, and it is only necessary to check over the equipment periodically and set the instruments. The cost of maintaining

the plant in first-class operating condition is low because of the use of rugged items of equipment and the use of special corrosion-resistant alloys where necessary. Annual maintenance cost rarely exceeds five per cent of the cost of equipment. While the recovery expense will vary with the cost of utilities and the recovery conditions in general, experience has shown that this figure may in some cases be less than 0.2c. per lb., and practically never exceeds 1c. per lb. recovered solvents.

Some of the outstanding advantages of activated carbon which are causing such adsorption systems to replace other methods are: (1) recovers solvent vapors in concentrations safely below the flammable range; (2) recovers all types of volatile solvents; (3) recovery expense low; (4) recovers solvents efficiently in presence of water vapor; (5) recovers solvent vapors with high over-all efficiency; (6) recovery plant may be completely automatic in operation, and (7) recovery plant investment is moderate.

Drying Psychrometry

By *EDITORIAL STAFF*. In process industries more and more drying problems are becoming problems of conditioning air or a gas to obtain efficient vaporization. Because heat is an expensive item among process costs, engineers are paying greater attention to heat economy.

DRYING, as used by the chemical engineer, is a term for the process of removing water (or other liquid) from a solid (or nearly solid) material by vaporization. In every case the moisture is removed in one of two ways—by sweeping it out with air or by "pulling" it out with a vacuum.

Here, we shall confine ourselves to drying with air (or other gas), for that is the field in which psychrometry is involved.

In a good many cases conditioned air is not emphasized as the medium for moisture removal. For instance, a drum dryer is not ordinarily considered as an air dryer, yet the moisture diffuses into the air and if an atmosphere of saturated air were maintained adjacent to the surface of the material, no drying would take place. The humidity of the air is not always considered in a rotary dryer, yet it has an important effect on the performance of the dryer.

On the other hand, there are many kinds of dryers and many drying jobs where the temperature, humidity and volume of air are all controlled very carefully. In these cases a number of factors are to be considered from two standpoints—the material to be dried and the air itself.

How much moisture is to be removed? This can be ascertained from the desired final condition of the material. It has an important bearing on the rate of drying. Above a certain critical moisture content, the rate is constant. During this so-called constant-rate period surface water is evaporated together with moisture which rises to the surface as fast as evaporation takes place. Below the critical moisture content, the rate of drying falls off due to the fact that the resistance to diffusion of water through the material prevents its rising to the surface fast enough. Thus the desired final moisture content determines how much drying can be done at each rate.

Maximum and minimum temperatures may be fixed by the characteristics of the material. Decomposition or other chemical reactions must be avoided. Likewise the physical form of the product may be affected by temperature.

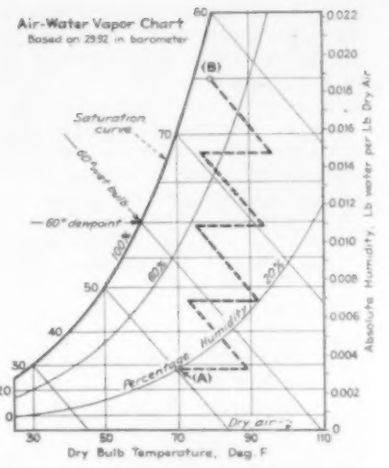
Both sensible and latent heat must be supplied to the material. Requirements may be calculated easily enough from the initial and final temperatures, the specific heat, the amount of moisture to be removed and the weight of material. This heat may be supplied either by the air or by direct heat or by both.

From the standpoint of the air, the amount of moisture removal determines the humidity change that must take place. The above mentioned considerations limit the temperatures that may be used. A third variable, the quantity of air circulated, is likewise fixed by the moisture removal and heat requirements.

The big problem usually is to effect a balance between temperature and humidity. This is made easier by the concept of *drying potential*. Drying potential is merely the difference between the partial pressure of vapor in the air and the vapor pressure of the liquid in the material. The only true measure of the drying effect of air is its change in vapor pressure. This quantity is the driving force which produces drying. It may be compared to voltage in an electrical system. Some experts would discard the arbitrary term *relative humidity* and substitute *drying potential*. Thus the psychrometric chart would have lines of constant vapor pressure difference. This system is used by some European investigators (see Hirsch's "Die Trockentecknik"). The interesting thing about drying potential is that a given vapor pressure difference will produce a given drying effect whether the air is at 30 deg. or 300 deg.

For a given drying problem air of low humidity is not always the most desirable. Sometimes the required drying potential will be taken in a condition of high humidity purposely. For example, in the drying of ceramic ware, if the surface is dried much faster than the moisture diffuses to the surface, the surface will shrink, causing checking and cracking. Air of higher humidity prevents this.

Recycling and reheating of air results in increased efficiency over the single-pass drying process. Instead of being used once and discarded, the air is reheated, allowed to take up moisture, again reheated, etc. On the accompanying chart the incoming air is at 70 deg. and 20 per cent humidity (point *A*). After four cycles in which heating is carried only to 95 deg. F., the air is discharged at 79 deg. F. and 85 per cent humidity (point *B*). If the same amount of drying is to be done by the same amount of air in a single pass, the air would have to be heated to 145 deg. F.



Reheating cycle for air used in removing moisture from a solid material. Air entering the dryer is of composition represented by point *A* and exit air is at *B*

In some cases it is desirable to carry this idea further—to dehydrate the air and recirculate again. Various kinds of dehydration methods (as described elsewhere in this section) may be used for this purpose. Recently there has been discussion of the possibility of reconcentrating the absorbent used in this process (such as lithium chloride) by multiple-effect evaporation. For large installations, some designers claim, this process can be made economical.

Though much research has been done in this field, there are still many phases of drying that are not thoroughly understood. Even parts of the fundamental theory expressed above are disputed by some investigators, though accepted by most chemical engineers. As more research is carried out, it is probable that many empirical methods of today may be replaced by more scientific and more economical methods of tomorrow.

A limited number of reprints of this 52-page Chem. & Met. Report are available at 50 cents each. Address the Editorial Department, Chemical & Metallurgical Engineering, 330 West 42d St., New York, N. Y.

Exterior and interior views of a German plant where sulphuric acid is made from calcium sulphate, clay and coke coal

Ersatz Raw Materials For German H_2SO_4

KARL FALK *Fresno College, Fresno, California*

Chem. & Met. INTERPRETATION

In line with their country's policy of self-sufficiency, German chemical engineers have improved the process used during the World War for the production of sulphuric acid from anhydrite. While it is an interesting method, as with many of such substitutes, its usefulness is limited to countries wherein ideologies or war or both dictate that domestic raw materials be used. Only under such conditions is it possible to make use of less efficient and more expensive methods and materials.—*Editors.*

SUPPLYING RAW MATERIALS for Germany's annual production of 2,800,000 metric tons of sulphuric acid has become a problem since the outbreak of the war. Iron pyrite, basic raw material for processes used heretofore, has accounted for three-quarters of the Reich's needs, while the remainder has come from zinc and copper ores and a fraction has been obtained as sulphur from coal. Since Germany produces only a small amount of iron pyrite (in the Meggen, Waldsassen, and Helmstedt districts), two-thirds of her pyrite requirements have had to be imported, chiefly from Spain, Norway, Cyprus and Italy.

Faced with the possibility of being cut off from these sources of supply, I. G. Farbenindustrie has now undertaken large-scale production of sulphuric acid based exclusively on domestic raw materials. The process used is claimed to be an improvement over that of the World War when Germany was cut off from pyrite supplies.

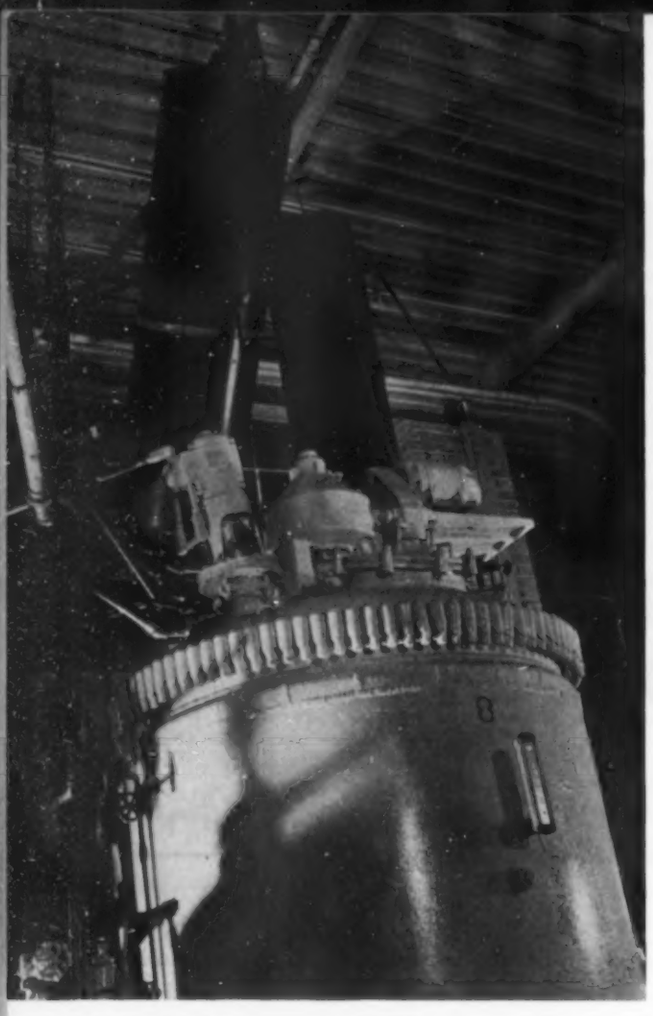
The rather crude World War processes, which were later abandoned because of high costs, were based on calcium sulphate. This was converted with synthetic ammonia and industrial gases to lime and ammonium sulphate, thereby saving sulphuric acid then used to produce ammonium sulphate fertilizers. Residual calcium sulphide from the Leblanc soda process was also used as a raw material for sulphuric acid manufacture. Mixed with a magnesium chromate solution, the sulphur was expelled as H_2S from rotary kilns, mixed with air and reduced to sulphur in Claus ovens (bauxite used as contact mass) or to sulphuric acid (Rhenania process).

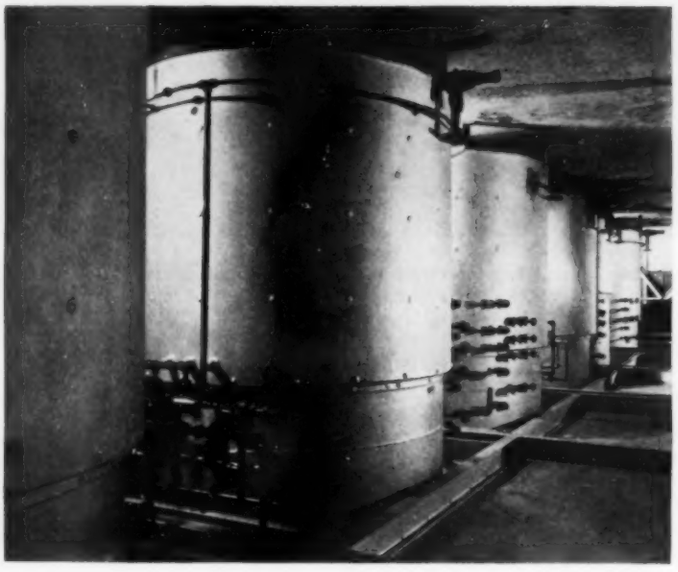
The present Müller-Kühne process, named after its inventors, was developed in the I. G. Bayer, Leverkusen, plant which continued production from the World War until 1931 on an experimental basis. In 1937 and 1938 a large plant was erected in Wolfen and after one year of regular operation it is claimed that the improved process is technically, and under present circumstances, economically feasible. If widely used, this will give the Reich an alternative sulphuric acid producing method to supplement, if not to supplant, present processes which depend upon imported sulphide ores.

The I. G. process now being used in the Wolfen plant which has a yearly capacity of 80,000 tons sulphuric acid (65,000 tons SO_3) and 75,000 tons cement, proceeds, as did the World War process, from calcium sulphate available in unlimited quantities in Central Germany.

Clay (or clay slate) is another abundantly available material needed in the process. It is pre-dried to remove moisture and is then mixed and ground with the anhydrite and coke into a raw meal whose composition is such as to permit complete reduction of the $CaSO_4$ to SO_2, as well as to contain the correct mixture for a good quality cement. This charge is then roasted in a rotary kiln (the Wolfen plant has two ovens, each 70 meters long) heated with a coal dust flame. The SO_2 is driven out and the hydraulic clinker is heated to a temperature of 1,400 deg. C. After being stored for a month, the clinker is mixed with a two per cent addition of gypsum and is ground up in a rotary ball mill. It is then stored in silos from which it is filled directly into sacks. The two per cent gypsum supplement helps to control the binding time of the cement which is marketed as a standard brand of Portland cement.

The H_2S gas driven off from the kilns is freed of foreign particles in huge dust chambers and is cooled and washed in scrubbing towers. Air is then added to provide necessary oxygen to form SO_3. From this point on, the usual SO_3 contact process with vanadium as a contact mass is used.

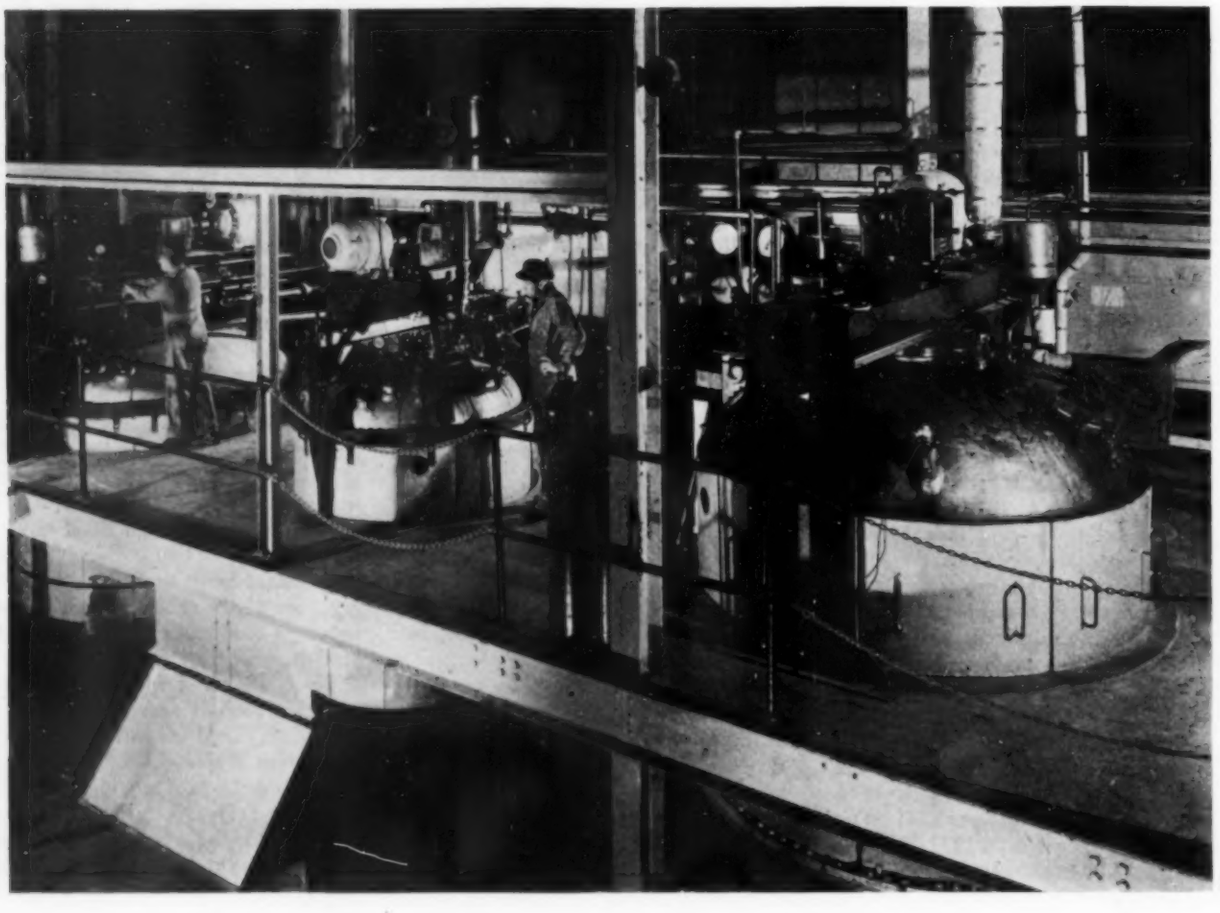




Steam jacketed vessels in which, under uniform temperature, phenol-formaldehyde resins are produced

Left—Raw materials for the urea-formaldehyde are pretreated and cooked in a series of glass-lined, steam jacketed kettles

Below—Cooking kettles for making bases for alkyd, modified phenolics and non-phenolics



Synthetic Resins for Surface Coatings

JAMES A. LEE *Managing Editor, Chemical and Metallurgical Engineering*

Chem. & Met. INTERPRETATION

One of the most remarkable accomplishments in the field of chemistry during the past few years is the growth of the new synthetic resins industry. The spectacular expansion is due in no small part to the important role these materials are playing in the formulation of superior paints, varnishes, lacquers, inks, textiles and many other kinds of surface coatings. One of the largest producers of the resins for surface coatings is Reichhold Chemicals, Inc. The Detroit plant of that company is just as up-to-date as the products being made are modern.— *Editors*

THE SPECTACULAR SPREAD of synthetic resins in the form of molded or cast objects has attracted attention all over the world. However, relatively little is known by "the man in the street" about the use of these remarkable materials in liquid form, since they cannot be so easily seen in paints, enamels, textiles, printing inks, paper, lumber, rubber and a host of many other products. The applications of synthetic resins in soluble form are increasing at an amazing pace as is exemplified by the growth of Reichhold Chemicals, Inc., of Detroit, Mich., one of the largest producers specializing in the soluble types.

In 1925, Henry Reichhold, only a few years removed from the college campus, realized the possibilities offered by synthetic resins. He secured a few kettles and started in business in the heart of the automobile industry. At the present time his organization has plants not only at headquarters in Detroit, but also at Elizabeth, N. J., Brooklyn, N. Y., Liverpool, Paris, Sydney and a plant is in process at Buenos Aires. This rapid expansion illustrates the innumerable achievements of these new resins and bears testimony to the aggressiveness of the chemists and engineers whose skill in practicably applying the properties of synthetic resins have developed their production and distribution into a great industry.

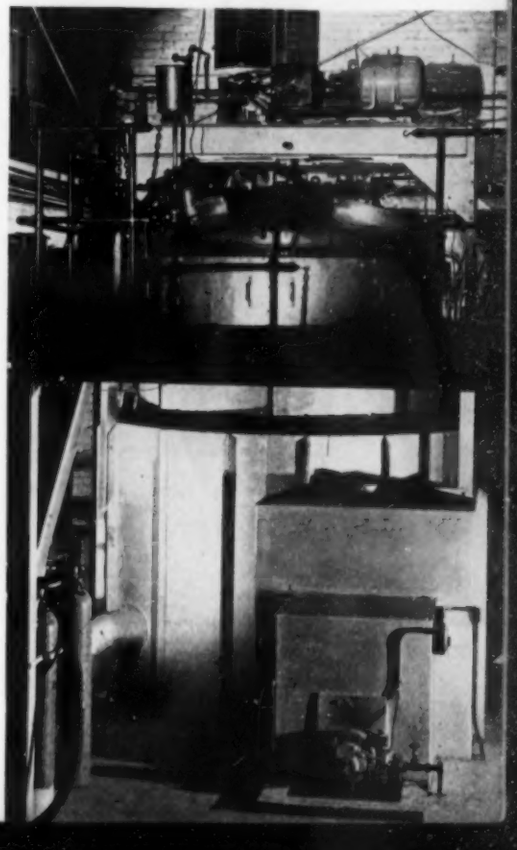
An impressive list of resins for surface coatings are manufactured in the several plants of the Reichhold company. Among the most important are: pure phenol-formaldehyde resins, modified phenolics, non-phenolics (maleic acid resins), alkyd resins, urea resins, ester gum, and processed copals; also catalyzed vegetable oils, and, in addition, such raw materials as phthalic anhydride and glycerine.

The Detroit plant is located on the Grand Trunk railroad system which assures adequate shipping facilities and just off famous Woodward Avenue at a point about ten miles from the heart of the city.

Each department or group of products is housed in an individual brick and steel fire-proof building in order to reduce the fire hazards to a minimum. They are well ventilated and lighted. An unusual feature is the use of a voice amplifying system instead of the customary automatic signaling system. It has proved to be very satisfactory in this plant.

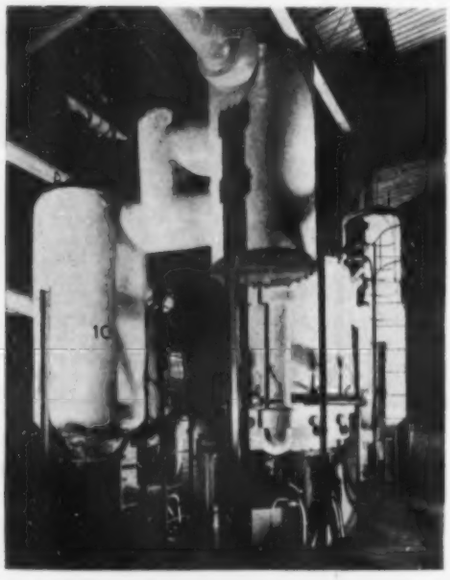
The liquid raw materials are stored in large steel tanks in the plant yard. Phenol, rosin, fossil gums and filtering medium are kept under cover until required. The fluids are conveyed to the pretreatment and processing kettles by remote controlled pumps, while the solids are lifted to the charging floors by portable elevators.

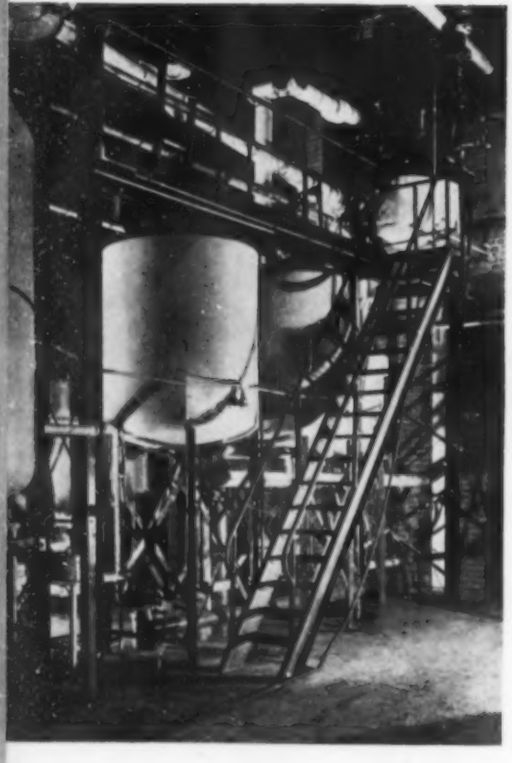
For the most part the processing equipment throughout the plant is constructed of plain iron and steel. However, in certain cases such special construction materials as stain-



In the preparation of modified phenolic resins raw materials are not pretreated but are pumped directly to 18-8 stainless steel vessels. These kettle are heated by oil

less steels are used to prevent discoloration of product and corrosion. The pretreatment tanks in which the materials are blended or aged in the production of pure phenolic resins are steam jacketed and equipped with agitators on a vertical shaft rotated from above. The cooking kettles in this department are oil-fired aluminum vessels. Here, as in all cases where resins are being processed, an atmosphere of carbon dioxide is kept above the surface of the solution during cooking in order to prevent darkening of the compound.





In the preparation of modified phenolic resins the raw materials are not pretreated, but are pumped directly to the 18 chromium-8 nickel stainless steel vessels. These kettles are heated by oil burners.

The alkyd resins too are processed in stainless steel kettles, with agitators on a vertical shaft and heated by oil burners. These resins are put into solution in plain steel mixing tanks. The resin is added to the kettle containing the mineral spirits, toluol, xylol, naphtha or other solvent or combination of solvents and the mixing action is accomplished by top or side entrance agitator.

Urea resins are processed in glass-lined vessels, steam jacketed and agitated from a vertical shaft. A similar type of kettle is also used for the aging and pretreating.

The pure phenolic resins, after a certain point in the cooking operation has been reached, are quickly cooled in order to prevent further reaction by draining from the kettle into shallow steel pans or trays to a depth of not greater than one inch. After it is cool the resin is broken into small pieces and loaded into drums for shipment to varnish, enamel and other manufacturers who use it in formulation of their products.

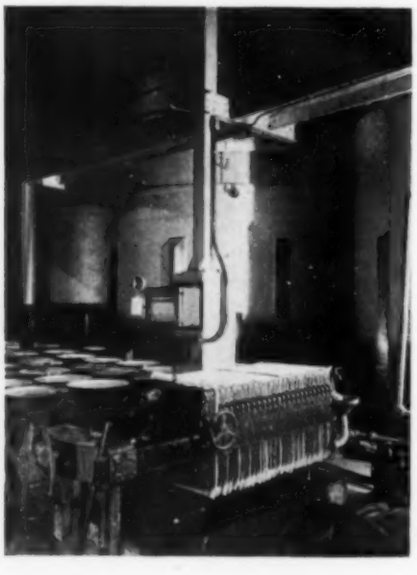
At the end of the cooling the modified phenolic resins are handled differently from the pure phenolics. The molten resin flows into a gigantic cooling tray, 20 in. deep, in batches varying from seven to eight tons each and, after cooling and hardening, which requires from 24 to 36 hours per batch, it is broken with heavy sledge hammers and shoveled through loading chutes into barrels traveling on a roller conveying system to storage or railroad cars. The bottom of the large tray is slightly more than the height of a barrel from the floor. This height permits easy filling of the barrels. The conveyor delivers the barrels to an electric vibrator which shakes the resin down tightly. When this is done the barrels are weighed.

In the same building and from even larger kettles certain grades of the modified phenolics while in a molten state, are run directly into steel shipping containers which are filled and weighed at one and the same time. Then the drums travel by roller conveyor to a cooling platform where, when sufficiently cool, they are sprayed with a coating of aluminum paint.

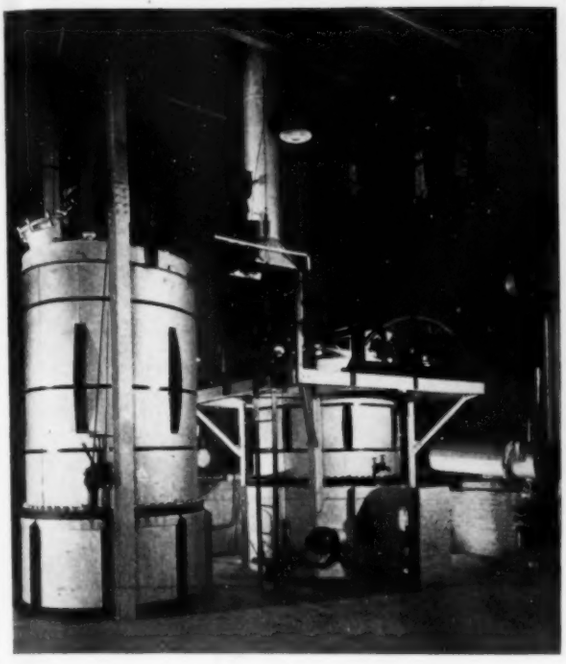
After the alkyd and urea resins have been thinned by the solvents they are passed through paper and duck in a plate and frame filter press to remove the clarifying agent and impurities. The solutions are then run directly into steel drums on scales with automatic shut-offs, guaranteeing uniform weight. Drum heads are stenciled and the containers conveyed to the final painting operation where they are completed for shipment.

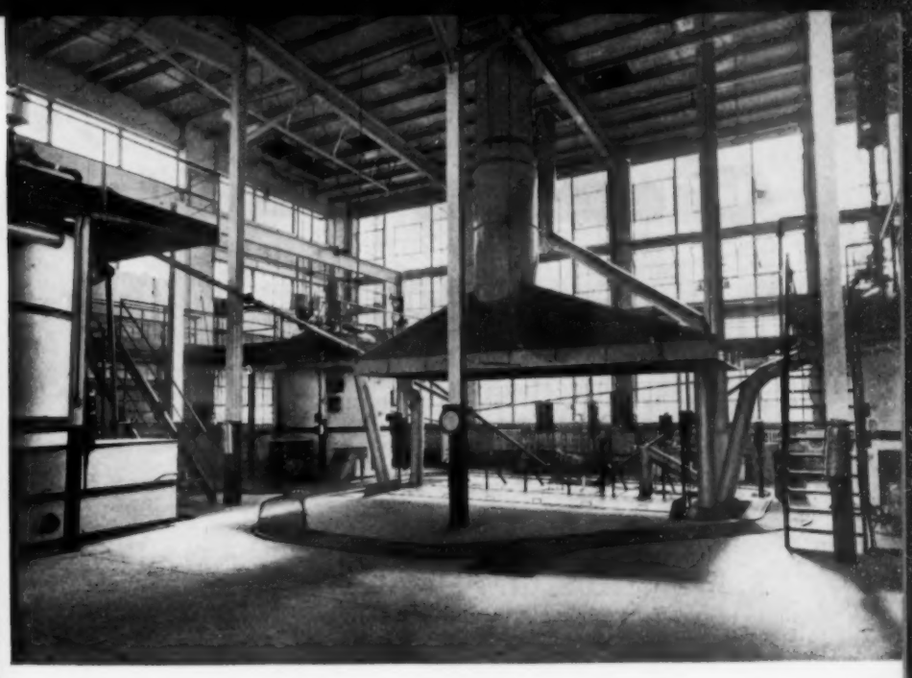
The ester gum-copal department, like all others in this plant, is housed in modern buildings and is equipped with improved production facilities. The rosins for esterification are received in tank cars in the warm months of the year from which they can be easily removed by melting, and in the winter the rosin reaches the plant in steel drums. In either case the gum is first heated in a gas-fired Monel preheating tank which has a capacity of 13,000 lb. The tank is under a hood which removes all fumes.

In the premelting tank the gum is held at a specific temperature for a definite length of time. The molten gum is then pumped through a series of sieves and strainers into an esterifying still. This vessel is constructed of Monel metal and is electrically heated. The heat is kept constant and the temperature charted and recorded by a group of electric, ther-



Alkyd resins are thinned with one or a combination of solvents, then filtered and put into drums for shipment. On the left are views in the phthalic anhydride-glycerine department. In addition to these raw materials Reichhold also produces some other materials.



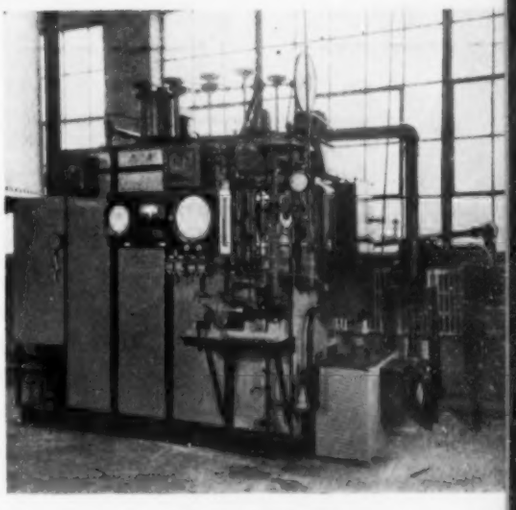


Left—Still in which Congo copals are fused, esterified and modified. Also, blending tank for mixing batches. Above—Ester gum processing with premelter in center

mostatic and recording instruments.

When esterification is complete, the liquid gum is pumped into filling tanks, from which it is run directly into steel shipping containers. These drums travel on a roller conveyor across the platform scale on which they are filled and from there to an out-of-doors platform where the gum hardens. Immediately after the drums cool to a temperature of 250 deg. F., the lids are locked in position, a coat of aluminum paint is applied and the head stenciled. After being allowed to cool thoroughly, drums are rolled into freight cars, trucks or trailers and routed to consumers in all parts of the country.

At one end of this same building is the fossil gum department. The Congo copals are raised to the charging platform around the kettle by portable elevators. Here they are fused in an oil-fired aluminum kettle, esterified and modified. When this process is completed the hot gum is pumped to a 40,000 lb. blending tank for intermixing several individual batches of processed fossil gums. These esterified and modified copals meet many requirements of the paint, varnish and lacquer of industry.



Tung oil is treated to render it more efficient for paint and varnish formulation

Typical Synthetic Resin Specifications

Type	Color	Acid Number	Melting Range °F.	Average Drying Time: Dust Free Hours	Average Drying Time: Dry Hours	Pounds per Gallon	Solubility: Alcohols	Solubility: Acetates	Solubility: Coal Tar Solvents	Solubility: Mineral Spirits	Solubility: Turpentine	Solubility: Drying Oils
	X	8–12	625°–650°	2–3	8–10	9.17–9.58	Ins.	S.C.	S.C.	2–3	S.C.	S.C.
	F-E	8–12	625°–650°	2–3	8–10	9.17–9.58	Ins.	S.C.	S.C.	2–3	S.C.	S.C.
Pure Phenolic	K-I	2–5	158°–176°	1½–2	10–12	8.75–9.08	S.C.	S.C.	S.C.	1–1	S.C.	S.H.
	F-E	10–15	181°–194°	1½–2	10–12	8.75–9.08	S.C.	S.C.	S.C.	1–1	S.C.	S.H.
	F-E	55–60	198°–215°	1½–2	8–10	10.50–10.83	S.C.	S.C.	S.C.	1–1	S.C.	S.H.
	I-H	85–105	275°–295°	½–1½	4–6		S.C.	S.C.	S.C.	Ins.	Ins.	S.H.
Modified Phenolic	M-K	15–20	215°–232°	1½–2½	6–8	9.17–9.50	Ins.	S.C.	S.C.	2–3	S.C.	S.C.
	H-G	15–20	215°–232°	1½–2½	6–8	9.17–9.50	Ins.	S.C.	S.C.	2–3	S.C.	S.C.
	K-I	15–20	176°–194°	2–3	7–9	9.33–9.66	Ins.	Ins.	S.C.	2–3	S.C.	S.H.
	I-H	15–20	208°–228°	1½–2½	6–8	9.33–9.66	Ins.	S.C.	S.C.	2–3	S.C.	S.H.
	I-H	15–20	230°–257°	1–2	4–6	9.66–10.00	Ins.	S.C.	S.C.	1–1½	S.H.	S.H.
	WG-N	17–22	230°–250°	1½–2½	6–8	9.42–9.75	Ins.	S.C.	S.C.	Ins.	S.C.	S.H.
Non-Phenolic	M-K	22–28	230°–248°	½–1	6–8	9.50–9.83	Ins.	S.C.	S.C.	Ins.	S.C.	S.H.
	M-K	17–22	199°–215°	2–3	7–9	9.50–9.83	Ins.	S.C.	S.C.	1–2	S.C.	S.C
	K-I	17–22	199°–215°	2–3	7–9	9.50–9.83	Ins.	S.C.	S.C.	1–2	S.C.	S.C.
Phenolated Copals	M-K	40–45	268°–302°	1–2	4–5	9.17–9.50	Ins.	S.C.	S.C.	1–1	S.C.	S.H.
Esterified Copal	E-D	10–15	185°–200°	1½–2½	6–8	8.75–9.17	Ins.	S.C.	S.C.	Ins.	S.C.	S.C.
Fused Copal	E-D	80–85	165°–176°	2–3	7–9	8.75–9.17	Ins.	S.C.	S.C.	Ins.	S.C.	S.C.
Modified Copal	I-H	15–20	176°–194°	1½–2½	6–8	8.83–9.17	Ins.	S.C.	S.C.	Ins.	S.C.	S.C.
Pure Rosin Ester	M-K	8–12	165°–178°	1¾–2½	7–9	9.17–9.58	Ins.	S.C.	S.C.	2–3	S.C.	S.C.
	G-F	15–20	129°–143°	2–3	8–10	9.17–9.58	Ins.	S.C.	S.C.	2–3	S.C.	S.C.
	WG-N	115–130	130°–150°	2–3	10–11	9.17–9.58	S	S.C.	S.C.	2–3	S.C.	S.C.

COLOR: All hard resin colors graded according to U. S. Department of Agriculture Rosin Standards.

DRYING: Time periods specified represent averages on properly formulated varnishes of from 15 to 20 gallons long, except pure phenolics figures which are on varnishes from 30 to 50 gallons long.

SOLUBILITY: "Ins." means insoluble; "S.C." — soluble cold in any proportion, and "S.H." — soluble hot in any proportion. Figures indicate maximum solvent tolerance without cloudiness or precipitation, the first representing resin and the second solvent.

Chemical Industry on the Niagara Frontier

R. B. MacMULLIN, F. L. KOETHEN

and C. N. RICHARDSON*

Chem. & Met. INTERPRETATION

A vast and varied chemical industry exists along the Niagara Frontier. Chief reasons are cheap, reliable power, favorable climate, inexhaustible supply of cooling water, a good labor market and unexcelled water, rail and air transportation facilities. Niagara Falls is "Electrochemistry's Capital" and the utilization of the byproducts of power makes an interesting chapter in chemical engineering history. The early development of the American and Canadian chemical and related process industries along the frontier and their present status are critically reviewed, with many outstanding achievements noted in this very comprehensive paper.— *Editors.*

THE NIAGARA FRONTIER not only has a large chemical industry, but it is also distinctive in the nature of its products and interesting because of its industrial history and of the personalities who have made it. Many of the large industries of the area were established by pioneers in their fields and their impacts on the industrial balance of the country were momentous. These industries located there because of abundance of very cheap power; unlimited supply of cooling water; and excellent transportation situation; a climate that has few extremes of temperature—no floods, no earthquakes, no tornadoes; and because the principal markets of the country lie within a radius of about 500 miles.

The industries in Niagara and Erie Counties produced, according to the 1937 Census, $1,078,000,000 worth of products of which the authors' estimate that $425,000,000 were products of chemical or allied industries. Allowance for similar manufactures on the Canadian side of the Niagara brings the total for chemical industry to well over half a billion dollars annually.

ELECTROCHEMICAL CAPITAL

Nowhere in the world is congregated such an extensive and varied group of electrochemical industries as are found in the Niagara Peninsula. The bulk of this industry is engaged in electrolysis of salt and the making of ferro alloys, carbide and artificial abrasives, but an almost infinite number of other products is produced, many being derivatives of the basic materials already mentioned.

Six plants at Niagara Falls depend on the basic reaction: Salt + Power = Alkali + Chlorine. The combined chlorine capacity of this group is over 400 tons daily, making this the greatest chlorine-producing area in the United States. The salt comes from the nearby Retsof Mines of the International Salt Co.; and the power[1] of course, from Niagara's waters.

* Mr. MacMullin and Mr. Richardson are in the research department of Mathieson Alkali Works in Niagara Falls, N. Y. Mr. Koethen is technical director of American Lubricants, Inc. Their paper was presented at the Buffalo-Niagara Falls meeting of the American Institute of Chemical Engineers, May 13-15, 1940.

[1] Niagara's hydro power is 100 per cent load-factor power, and that makes

Chemical Process Industries in the Niagara-Buffalo Area

1. Scholler Bros. 2. Canada Hair Cloth. 3. Guarantee Silk, Dye & Finishing Co. 4. Interlake Tissue Mills. 5. Alliance Paper Co. 6. Garden City Tissue Paper Mills. 7. Prov'l. Paper Mills. 8. Vegetable Parchment Mills. 9. Exolon Co. 10. Ontario Paper Co. 11. Stokeshard Rubber Co. 12. Standard Steel Co. 13. Canadian Atlas Steel Co. 14. Electrometallurgical Co. 15. Union Carbide Co. 16. International Nickel Co. 17. Canada Cement, Ltd. 18. Canada Wineries, Ltd. 19. American Cyanamid, Ltd. 20. Burgess Battery Co. 21. Oneida Community, Ltd. 22. Carborundum Co. 23. Norton Co. 24. Chateau Gay Winery. 25. Niagara Smelting Co. 26. Titanium Alloy Mfg. Co. 27. Vanadium Corp. 28. Republic Carbon Co. 29. General Abrasive. 30. Pittsburgh Metallurgical. 31. National Carbon Co. 32. American Treibach. 33. Niagara Wall Paper Co. 34. Aluminum Co. of America. 35. International Paper Co. 36. Acheson Graphite Co. 37. Gredag Corp. 38. Carborundum Co. 39. Mathieson Alkali Works. 40. E. I. duPont de Nemours & Co., Inc. 41. Alox Chemical Co. 42. Niagara Alkali Co. 43. Hooker Electrochemical Co. 44. Oldbury Electrochemical Co. 45. Varcum Chemicals. 46. Niacet Chemical Corp. 47. Union Carbide Co. 48. Comstock & Westcott. 49. Great Lakes Carbon Co. 50. International Graphite Corp. 51. USL Battery Corp. 52. Chisholm Ryder Co. 53. Niagara Falls Sewer Authority. 54. Cowles Detergent Co. 55. Norton Laboratories. 56. Harrison Radiator Co. 57. Simonds Saw & Steel Co. 58. Buffalo Pump Co. 59. Tonowanda Steel Co. 60. Becker & Moore Co. 61. Van Raalte Co. 62. Remington Rand, Inc. 63. General Plastics. 64. International Paper Co. 65. Spaulding Fibre Co. 66. Buffalo Slag Co. 67. Wickwire Spencer Steel Co. 68. Buffalo Electrochemical Co. 69. Semet Solvay Co. 70. Dunlop Tire & Rubber Co. 71. E. I. du Pont de Nemours & Co., Inc. (Cellophane). 72. E. I. du Pont de Nemours & Co., Inc. (Rayon). 73. Linde Air Products Corp. 74. Huntley Station, Niagara Hudson Power Co. 75. American Radiator Co. 76. American Brass Co. 77. Pratt & Lambert, Inc. 78. American Boron Co. 79. Buffalo Sewer Authority. 80. Mentholatum Co. 81. Sowers Mfg. Co. 82. Worlds Dispensary Medical Co. 83. Hewitt Rubber Co. 84. Republic Light Heat & Power Co. 85. Iroquois Gas Corp. 86. Spencer Kellog & Sons, Inc. 87. Pillsbury Flour Co. 88. Heckers H. O. 89. Quaker Oats Co. 90. Pierce & Stevens, Inc. 91. General Mills. 92. Harris Soap Co. 93. Lucidol Corp. 94. McDougall-Butler Co. 95. Michigan Limestone & Chem. Co. 96. Kelly Island Lime & Trans. Co. 97. Great Lakes Portland Cement Co. 98. Donner Hanna Coke Corp. 99. General Chemical Co. 100. National Aniline & Chemical Co. 101. U. S. Rubber Reclaiming Co. 102. American Lubricants Co. 103. Hygrade Products. 104. Linde Air Products Corp. 105. Spencer Lens Co. 106. Buffalo Foundry & Mach. Co. 107. Archer Daniels Midland Co. 108. Socony Vacuum Oil Co. 109. Mann Bros. Co. 110. Republic Steel Co. 111. Bethlehem Steel Co. 112. Exolon Co. 113. Federal Portland Cement Co. 114. Philadelphia Quartz Co.

The chlorine industry dates from 1897 when the Mathieson Alkali Works established the Castner rocking mercury-cathode cell. The purity of the caustic produced in this cell has had a very favorable influence on the development of the rayon industry. The other companies all use diaphragm cells of various types. The Hooker Electrochemical Co. started with the Townsend cell in 1904. Of particular interest is the present Hooker type of cell in which the asbestos diaphragm is deposited on a screen as in making paper. Taking into account all installations, more chlorine is being made today in this cell than in any other type (See *Chem. & Met.*, July, 1938, pp. 354-8).

The Niagara Alkali Co. in 1907 took over the Roberts Chemical Co., founded in 1902. The Roberts cells were replaced by Billiter cells and later by Vorce cells. This company

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it particularly valuable for the chemical and metallurgical industries which require large blocks of power at or near this load-factor. It is not cheap for low load-factor use. For example, Niagara power is delivered at 100 per cent load-factor for 3 mills per kw.-hr. If it is used at 50 per cent load-factor, it will cost 6 mills per kw.-hr. Under similar conditions, steam-electric power at 100 per cent load-factor will cost 5 mills per kw.-hr. and at 50 per cent load-factor it will cost 6 mills per kw.-hr., the same as hydro. Below 50 per cent load-factor, steam power will be cheaper than the hydro.—Authors.

and the Isco Chemical Co. (1916) both manufacture caustic potash as well as soda. The Niagara Smelting Co. was organized in 1916 to manufacture aluminum; although this metal was never produced, the Wheeler chlorine cell has been operating successfully ever since.

The duPont Company (R. & H. Chemicals Division), in contrast to the aforementioned, electrolyzes fused salt, producing metallic sodium and chlorine. Back in 1895 the local plant was then known as the Niagara Electrochemical Co., which started out by electrolyzing anhydrous caustic for the production of sodium. Within the last decade the present cell, invented by J. Cloyd Downs (Schoellkopf medalist 1934) has greatly reduced the cost of sodium and made possible the great ethyl gasoline development.

The Oldbury Electrochemical Co. (1897) is now the only plant manufacturing chlorates. Both sodium and potassium chlorates and also perchlorates are made. Chlorate was formerly made by National Electrolytic Co. Various plants make inorganic chlorides. To name a few: CCl_4, SCl_2, $SiCl_4$, $TiCl_4$, $FeCl_3$, sulphuryl and thionyl chlorides, $SbCl_5$, $AlCl_3$, PCl_5, $COCl_2$ and of course, HCl.

The organic chlorination products are perhaps the most interesting. They include tetrachlorethane and trichlorethylene which find widely diverse applications as in the dry cleaning industry and in the mineral industry. Several plants chlorinate benzene and toluene, and make the benzoyl derivaties. Chlorpicrin, methyl chloride, dichloromethylstearate are also produced.

Byproduct hydrogen from electrolytic cells is utilized in two synthetic ammonia plants. Another plant carries out custom hydrogenation, and still another uses hydrogen for making methanol. Several plants burn the hydrogen with chlorine to make HCl.

The duPont company not only ships metallic sodium in bulk, but also utilizes it in the manufacture of sodium peroxide and sodium cyanide. Two large plants (duPont and Buffalo Electro-Chemical) make hydrogen peroxide and per salts. A third company, the Lucidol Corporation, makes benzoyl peroxide and controls a bleaching process in the vast flour mill industry, a large part of which is located in Buffalo.

Carbide.—The discovery of calcium carbide by Thomas Willson in 1892 marked the beginning of an astounding chapter in chemical history, with the scenes laid chiefly at Niagara Falls. One of the first, but not very successful plants, was built there in 1895. In 1898 the Union Carbide Co. was organized, to take over the operations at the Soo and at the Falls. The objective: to market carbide as a source of light and heat, the generated acetylene to compete with manufactured gas! The first contract with the Niagara Falls Power Co. was for 1000 hp. Today over 150,000 hp. is utilized at the Niagara plant in the manufacture of carbide and ferro-alloys. Starting with a large number of small rotary Horry furnaces, drawing 120 hp. each, the plant today operates tapping furnaces 200 times that size. The Wel-

Section of Niagara's Electrochemical Industries Showing Carborundum, Mathieson and R. & H. Plants

land, Ontario plant was built in 1914, and draws about 50,000 hp.

In 1904 the safe shipment of acetylene dissolved in cylinders of acetone was introduced; and shortly after safe automatic generators for acetylene gas were perfected. Thus was ushered in the era of welding, which culminated in 1922 with the perfection of oxyacetylene welding technique. The Prest-o-lite, the Oxweld-Acetylene Co., and the Linde Air Products Co., all subsidiaries of Union Carbide and Carbon Corporation, supply the acetylene, the equipment, and the oxygen respectively, and all have plants in the local area. A recent development of more than passing interest is the shipment of liquid oxygen in 15-ton insulated tank cars, for use in local steel mills for descaling billets.

In 1926 the carbide furnaces were enclosed, thus providing a source of nearly pure carbon monoxide in large quantities. Carbide and Carbon Chemicals Corp. then built a plant to convert this gas with steam into CO_2 and H_2. These gases are now separated, and the former converted to dry ice, while the latter is converted, with additional CO, to synthetic anhydrous methanol. The dry ice is sold advantageously in the rich fruit and dairy area and the methanol in part is consumed locally by other Niagara industries.

The Union Carbide Co. supplies the Niacet Chemicals Corp. and the duPont Company with pure acetylene gas by pipe line. In the former plant is made a long line of acetic acid and vinyl derivatives, and in the latter plant, a variety of chlorinated solvents.

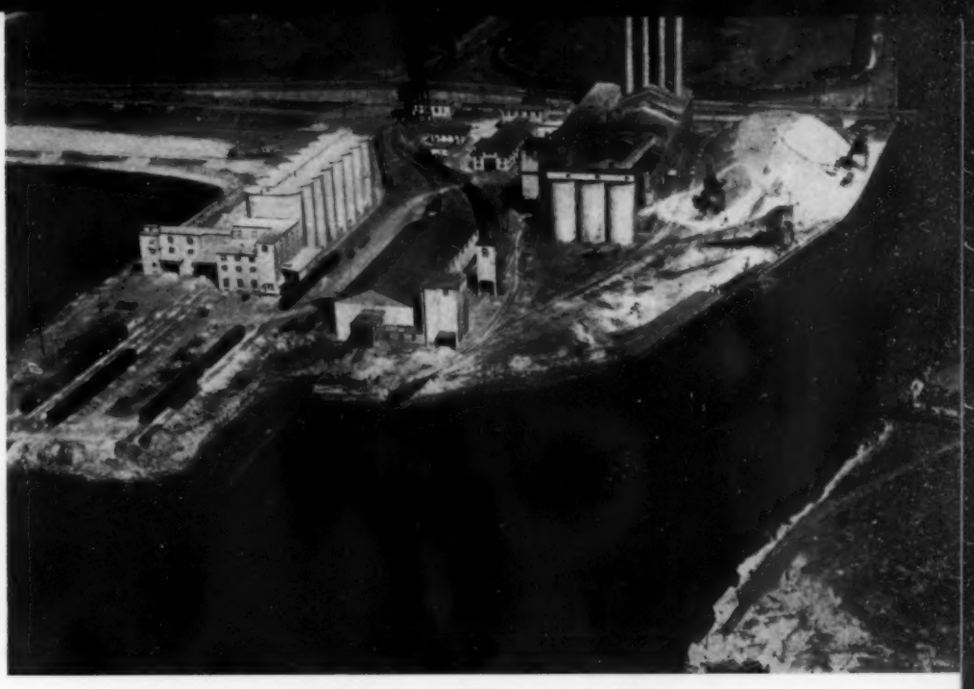
In 1909 the North American Cyanamide Co. built a plant in Niagara Falls, Ontario. Outside of the standby plant at Muscle Shoals, which was built for the government under Cyanamide Co. supervision, this is the only one of its kind in the Western Hemisphere. The basic material is calcium carbide, and the total furnace capacity approaches 100,000 hp. Nitrogen is furnished by the Claude process, and is reacted with carbide in a unique furnace to form calcium cyanamide. This finds wide use as a fertilizer as such, although a part is converted to sodium cyanide, ammophos, and other agricultural products. See *Chem. & Met.* Pictured Flowsheet for April, 1940, pp. 253-6.)

Abrasives.—Abrasive wheels of natural emery date back to 1875. The story of synthetic abrasives begins with Edward G. Acheson's discovery of silicon carbide in 1891. At first little more than a laboratory curiosity, he gave it the trade name "Carborundum." He obtained an order from a jeweler for 10 carats, at 40 cents a carat ($880 a pound), and went into business. In 1895 he moved to Niagara Falls where the hydroelectric development was just beginning. Large furnaces were built and its manufacture on a large scale began. Acheson soon left this venture to exploit synthetic graphite. His successor, and president today, is Frank J. Tone, to whom the first Schoellkopf medal was awarded in 1931 for his part in this extraordinary development.

In 1901 Jacobs developed Moissan's laboratory method of preparing pure fused alumina (corundum), and in 1905 L. E. Saunders adapted this to commercial production for the Norton Co. in Niagara Falls. This company in 1913 started the manufacture of silicon carbide at Chippawa, Ontario, and later, 1931, moved their Niagara Falls alumina operations to Chippawa. The Carborundum Co. was also early in producing fused Al_2O_3.

Graphite and Carbon.—In 1895 Edward G. Acheson discovered that if the temperature in his carborundum furnace was too high, the SiC decomposed. Silicon distilled off, leaving synthetic graphite. This encouraged him to found in 1899 the Acheson Graphite Co., which has led and still leads the world in the making of this important commodity. It was Hamilton Y. Castner, however, who discovered how to graphitize elemental carbon (1893). This became practical when carried out in the Carborundum type of furnace, many improvements being made by Acheson and Tone. Without graphitized anodes, the great electrolytic alkali and chlorine industry of today would not have been possible. Today there are three producers in the Niagara area: Acheson Graphite Co. (now a U. C. & C. subsidiary). The International Graphite and Electrode Co., and the Exolon Co. The Gredag Corporation, formerly an Acheson unit but now independent, manufactures graphite lubricants.

Phosphorus.—The Oldbury Electrochemical Co. began operations in 1897. They have manufactured white phosphorus by an electric furnace method continuously ever since. The process had been used in England, but located here because of cheap Niagara power. In 1927 Oldbury bought out the Phosphorus Compounds Co. and adjacent plant. From white phosphorus are derived a line of chemicals including red P, phosphorus sulphides, chlorides, hypophosphites, oxides, and phosphoric acid. The products are widely used in the match industry. Carbon monoxide, a byproduct of the furnaces, serves as one raw material in the manufacture of oxalic acid.[1]



Great Lakes Portland Cement Corporation Combines Water and Rail Facilities

[1] Editor's Note: The original paper from which this article was condensed appears in full in the April, 1940, issue, Transactions of the American Institute of Chemical Engineers. In it will be found a fascinating history of the industrial development of the Niagara area as well as more detailed information on the chemical and metallurgical industries of Buffalo and its environs.

Chemical Engineers Concentrate In Buffalo-Niagara Area

EDITORIAL STAFF REPORT

MORE THAN 500 members and guests of the American Institute of Chemical Engineers met in Buffalo on May 13, 14 and 15 for the 32nd semi-annual meeting—their fifth convention on the Niagara Frontier since 1910. Three technical sessions at which 18 papers were presented by 34 authors were supplemented by visits to 20 plants in the area. Four other papers, originally prepared for the second International Chemical Engineering Congress in Berlin in June, 1940 (now indefinitely postponed!) were read by title. An active local committee, representing both Buffalo and Niagara Falls, was under the honorary chairmanship of Frank J. Tone, president of the Carborundum Co., and was ably directed by R. B. MacMullin, general chairman, and Burrows Morey, vice-chairman. Lauren B. Hitchcock, chairman of the entertainment committee, provided a unique and thoroughly enjoyable social program that included a series of "honeymoon events" at Niagara Falls.

Chemical engineering's many diverse developments in theory and practice were reflected in all of the technical sessions at Buffalo. Brief abstracts of those papers that dealt specifically with plants and processes are presented first, followed by those concerned with fundamental studies of principles underlying the various unit operations.

Sewage Treatment—Buffalo's new sewage treatment works uses a primary sedimentation process followed by sludge digestion and incineration. Features of chemical engineering interest include the dewatering of the sludge on vacuum filters followed by Combustion Engineering Company's "flash-drying" process of solids disposal. Data collected and tabulated for the year 1939 suggest the application of a solids balance that should prove useful in other than sewage operations.—G. E. Symons, C. R. Velzy and Burrows Morey, Buffalo Sewage Authority.

Electrolytic Alkali—Few industries have grown as rapidly as the electrolytic alkali industry since its start in the United States in 1892. This growth has been characterized by the development of many types of cells, especially those of the diaphragm type. Within the last 15 years the producers of ammonia-soda alkali have also entered the electrolytic field, taking advantage of existing salt supply and cheap power available from high-pressure bleeder turbines.

The electrolytic alkali industry is also interesting because of related developments such as the nitric acid and salt process for chlorine, pumping of brine by pipeline from distant fields, production of salt by solar evaporation, mercury-arc rectifiers, various methods of cooling, drying, compressing and liquefying chlorine, caustic evaporation and salt recovery, production of rayon-grade electrolytic caustic soda, and new methods of packing and shipping chlorine and liquid castic soda.

Attention was called to the outstanding advance in the use of deposited asbestos diaphragms over the usual asbestos paper diaphragms made possible by unique cell construction.—R. L. Murray, Hooker Electrochemical Co.

Niagara Industries—A comprehensive paper on the development of American and Canadian chemical and related process industries along the Niagara Frontier, is presented in longer abstract on pages 338 to 341 of this issue—R. B. MacMullin, Mathieson Alkali Works, Inc., F. L. Koethen, American Lubricants, Inc. and C. N. Richardson, Mathieson Alkali Works, Inc.

Absolute Alcohol—In recent years absolute alcohol has become of increasing importance abroad when used in admixture with other materials for motor fuels. The usual method of production depends on an azeotropic distillation with a water-insoluble compound, such as benzol, but the high heat cost, the complicated and costly equipment necessary and other factors are cited as disadvantages of this method. By the use of ethyl ether as the entraining agent, the steam consumption may be reduced considerably, and the equipment greatly simplified, primarily because there is no ternary constant-boiling mixture of ether, water and alcohol, such as there is with all other materials which have been used heretofore.—T. O. Wentworth, Vulcan Copper & Supply Co. and D. F. Othmer, Polytechnic Institute of Brooklyn.

Alumina from Kaolin—Work of Cowles and others has shown that Al_2O_3 may be extracted from clay and similar raw materials by furnacing the aluminous material after mixing with limestone and soda ash, follower by leaching the furnaced product with water. By variations in composition of the furnace charge and processing temperatures, it was found possible to extract 85 to 90 per cent of the alumina from a kaolin containing 39.4 per cent Al_2O_3. The recovered alumina compared favorably in purity with that used at present by the aluminum industry. Less favorable results were obtained with a fire clay containing 27.5 per cent Al_2O_3 and a coal ash containing 13.9 per cent. Use of the residue remaining after the leaching operation seems to offer possibilities in the manufacture of portland cement.—Karl Kammermeyer, Drexel Institute and Alfred H. White, University of Michigan.

Drying Fibrous Materials—Samples of leather taken from a commercial tanning vat were dried in an experimental air-conditioned dryer controlling time, humidity and temperature to effect drying without "air-burning" the leather. Eighteen runs were made, varying from 68 to 192 hours, at humidities between 48.5 and 98.5 per cent and dry-bulb temperatures between 63.9 and 73.8 deg. F. Results indicated that humidity control is the most important factor in the drying of heavy leather and that temperature and air velocity are of secondary im-

General Committee, Western New York Section of A. I. Ch. E., Buffalo-Niagara Falls Meeting. Left to right members are: (standing) Riegel, Shepard, Eberlin, Hitchcock, Murray, Wallace, Crewson; (seated) Mrs. Hitchcock, MacMullin, Tone, Morey and Mrs. Morey

portance for reduction of time of drying and prevention of air-burns. —Frank C. Vilbrandt, Virginia Polytechnic Institute and J. W. Moore, Virginia Engineering Experiment Station.

New Heat-Transfer Medium—A molten mixture of inorganic salts has recently come into plant-scale use as a heating and cooling liquid. This mixture, consisting of approximately 40 per cent sodium nitrite, 7 per cent sodium nitrate and 53 per cent potassium nitrate can be used at atmospheric pressure in the temperature range of about 300 to 1,000 deg. F. It is found to be especially valuable at temperatures above the maximum limits of oil or Dowtherm. The mixture must be properly handled to reduce corrosion and thermal decomposition.—W. E. Kirst, W. M. Nagle and J. B. Castner, E. I. du Pont de Nemours & Co.

Heat Transmission—After careful study of previous investigations, an experimental apparatus has been designed and operated with particular attention to accuracy of temperature and heat-flow measurement. With this apparatus, individual heat-transfer coefficients from a vertical chromium-plated tube to boiling liquids have been determined for water, aqueous solutions of a wetting agent and of sugar, carbon tetrachloride and isopropanol at atmospheric pressure and for water at pressures below atmospheric. It has been shown that time is not an important variable when contamination is absent, but that liquid properties, heat flux density and pressure are. These facts have led to the formulation of a new correlation equation.—Thomas H. Insinger, Jr., and Harding Bliss, Yale University.

Steam Condensation—Condensing steam coefficients have been measured under film and drop-forming conditions in the same vertical-plate condenser. The effects of heat load, steam velocity and length of vertical surface have been evaluated. By means of a graphical correlation of the effect of steam velocity on dropwise coefficients, the true effect of length on such coefficients has been determined. Similar data confirm Nusselt's predictions for film coefficients.—F. L. Shea, Jr., University of Pennsylvania and N. W. Krase, E. I. du Pont de Nemours & Co.

Batch Distillation—A graphic method has been developed for computing the batch distillation curve (per cent distilled vs. distillate composition) for a binary mixture. It is necessary to know the vapor-liquid equilibrium diagram for the mixture, the distillation system efficiency expressed in theoretical plates, the reflux ratio and the charge composition. Benzene-toluene and benzene-ethylene dichloride mixtures were used.—E. H. Smoker, United Gas Improvement Co. and Arthur Rose, Pennsylvania State College.

Packed Towers—A rapid simplified graphical construction of transfer units is a method applicable to the general case wherein both gas and liquid film resistances are considerable.—G. Edwin White, College of the City of New York.

Vapor Pressure Correlation—It is shown that vapor pressures of liquids, of solids, of solutions having a non-volatile constituent, of solutions having two or more volatile constituents, of hydrates losing water by efflorescence and of other materials undergoing decomposition, give straight lines when plotted on logarithmic paper against values of the vapor pressures at corresponding temperatures of a referred substance. The slope of the line is equal to the ratio of the latent or other total heat quantity involved in the evolution of the vapor to the latent heat of the reference subject. This indicates the validity of the following equation:

$$\log P = \frac{L}{L'} \log P' + C$$

where P and P' are pressures and L and L' are molar latent heats respectively of two compounds always taken at the same temperature and C is a constant. Plots are made to illustrate the utility of this relationship with various materials in checking and correlating vapor pressure data; and it is shown to give lines more nearly straight than are obtained by any other method of plotting which has been suggested. Latent heats have been evaluated and checked: heat of fusion, of hydration, and dissociation, of dilution or solution, of chemical reactions, etc. are also shown to be related to the method and may be calculated.—Donald F. Othmer, Polytechnic Institute of Brooklyn. (For applications and construction of these charts see pp. 296-299.)

Heat Transfer—Results are presented of experimental values of non-boiling heat coefficients from condensing steam to water in annuli. The annuli measured were assembled from vari-

(*Please turn to page* 372)

Conversion Devices for

C. C. LEVY *Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.*

Chem. & Met. INTERPRETATION

Direct current power requirements of electrochemical industries and railroads were largely responsible for the invention and development of various rectification devices. Since it is economically preferable to transmit power as alternating current and since most electrochemical operations require direct current, much of the growth of the chlorine, electroplating and other electrochemical industries can be traced to solutions of the problem of making d.c. from a.c. In this article Mr. Levy, who has been prominently connected with the development of conversion devices, shows how various types have been developed to meet new needs and new demands. —*Editors.*

ELECTROCHEMICAL INDUSTRY was born before the conversion device. If such a machine had never been needed or had never been invented the industry would still have survived, but it could never have attained its present size and importance.

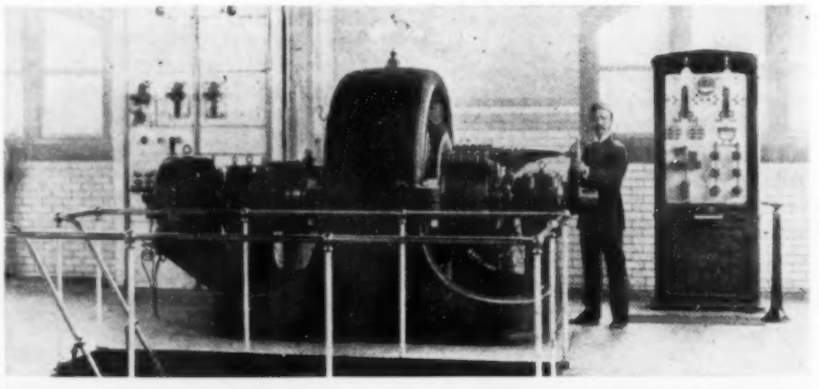
A conversion device is simply a link between an alternating current system and a load requiring direct current. When the conditions are reversed we call the device an inverter. A converter exists because of the necessity for obtaining direct currents for certain loads and the economic difficulty in directly generating the power required for them.

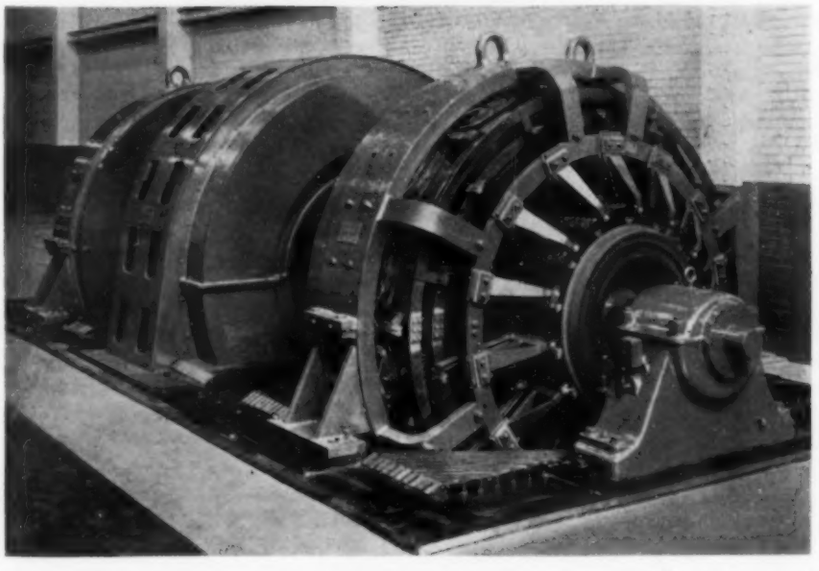
The electrochemical industry settled first at Niagara Falls, and prospered there for two reasons: (1) The direct current required could be generated by Niagara water power more economically than by steam power elsewhere, and (2) When the industry had just about reached the economic limits of the d.c. generating system with which it started, along came the alternating current system and the conversion device to give it new life and new strength.

Generation and transmission of polyphase alternating current on a large scale was first accomplished at Niagara Falls. The importance to all modern industry of that historic accomplishment can never be overestimated.

The results attained at that time may seem commonplace to us now, but it took courage, imagination and foresight to plan and carry through that undertaking when existing experience was so pitifully small.

We may smile now at some of the early plans to use Niagara power. One such plan was a system of pneumatic tubes supplied by turbine driven air compressors, with air lines leading to factories near the power house where compressed air motors would be used. Another proposed long lines of counter shafting spreading from the power house like a gigantic spider web. The final de-





Above are shown two conversion devices. At the top is a reproduction of an old photograph of an early converter. It is of historical interest being the first synchronous converter to supply direct current for street railway operation. Below is a modern three-unit fabricated-frame motor-generator set

Part of a Symposium on Power and Electrochemical Industry presented before the local sections of the A.I.E.E. and Electrochemical Society at Niagara Falls, Mar. 14, 1940.

Electrochemical Loads

cision to generate and transmit alternating current had a far greater influence on the growth of the electrochemical industry than was suspected at that time.

But the generation and transmission of power was not the only problem. The power had to be used in the industry as direct current and the conversion device was necessary.

It was another fortunate circumstance for the growth of the electrochemical industry that the generation and transmission of a.c. power was synchronized with the development of the converter and the large alternating current motor.

This point is well illustrated by a development that took place at the same time in the generation of direct current power.

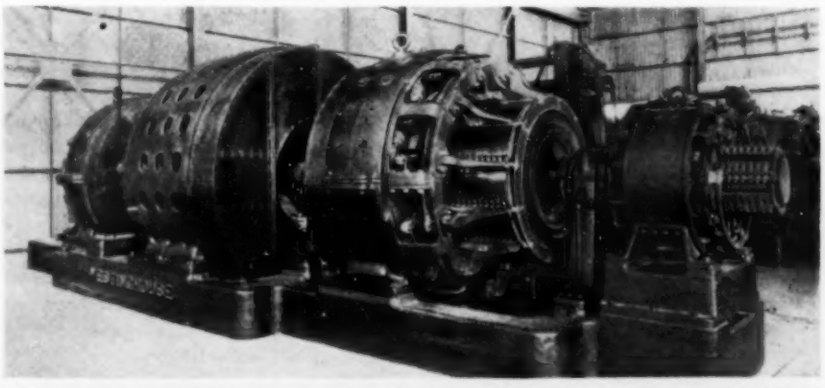
The first delivery of a.c. power from the Niagara Falls Power Company to the Pittsburgh Reduction Company in 1895 occurred at a time when the Niagara Falls Hydraulic Power and Manufacturing Company was already supplying d.c. power to several other electrochemical companies, all of which were situated close to the power house. However, each customer demanded a different d.c. voltage making efficient operation impossible. For example, the Pittsburgh Reduction Company used 300 volts, the National Electrolytic Company 135 volts as well as 175 volts, the Acker Process Company used the output of a 3,100-amp., 325-volt d.c. generator.

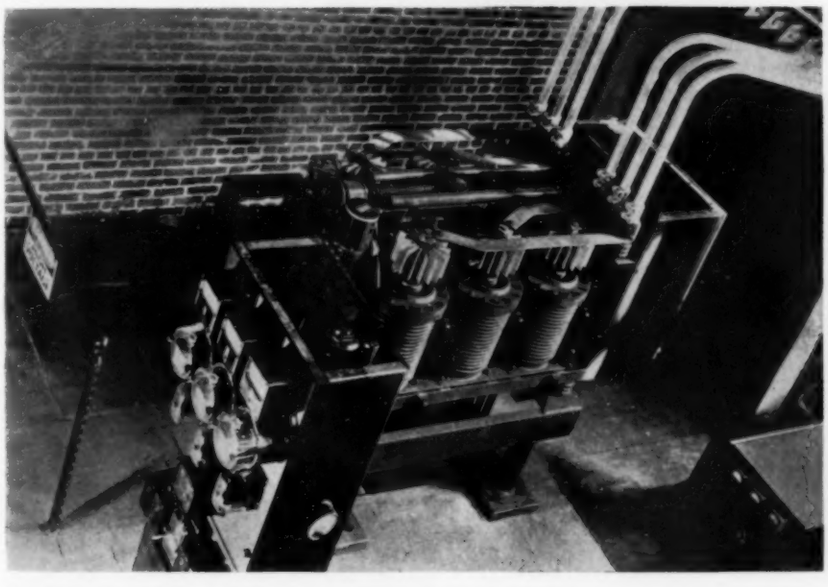
However, the rapid growth of the alternating current system and the development of the synchronous converter and the large a.c. motor for driving a d.c. generator completely displaced this haphazard generation of direct current.

The first synchronous converters were designed in 1893 by the Westinghouse Company and exhibited at the World's Fair in Chicago. This exhibit was followed by the first commercial units, two 200-kw., 25-cycle converters to be used as exciters for the Niagara Falls Power Company. The electrochemical industry in Niagara Falls soon followed with converters obtained from both the General Electric Company and the Westinghouse Company to supply d.c. from two phase a.c. power supply.

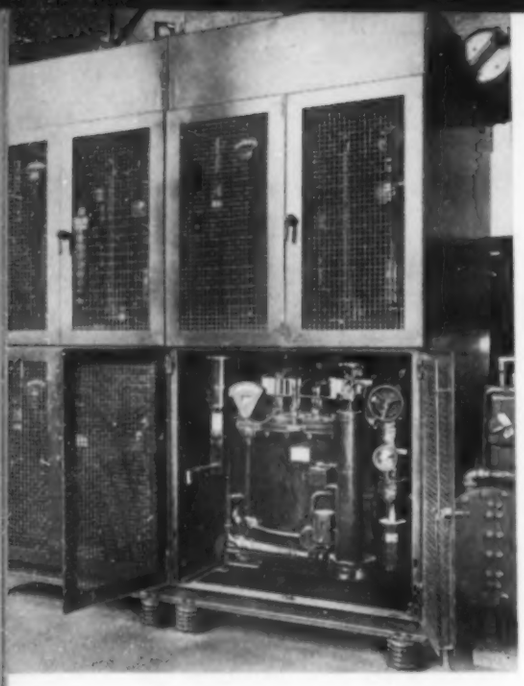
Initial difficulties in operation caused by "hunting" of the synchronous converter were overcome by the development of damper windings and thereafter the growth of the synchronous converter in this and other industries was extremely rapid.

An early problem in the use of converters for electrochemical loads was the voltage regulation of the d.c. The first answer was either to change the taps in the supply transformer, or to use an induction regulator in the primarly supply. The early tap changers were unsatisfactory because of contact troubles and the induction regulator was expensive. To meet this problem converter designers produced the synchronous booster converter. The first booster was supplied by the Westinghouse Company to the New York Edison Company in 1906, as an alternative to the induction regulator scheme of voltage regulation. In 1907 the General Electric Company brought out the "split pole" converter to accomplish the same results in a different manner. For some





The motor-generator (top), used in a copper refinery plant, is a typical three-unit set of cast type construction. Below is a six-tank experimental Ignitron rectifier, installed at the Massena Plant of the Aluminum Co. of America. Note the rectifier switchboard and control cabinet for excitation generator



Above are shown examples of the two static conversion devices used by electrochemical industries. At the left is a 6,000-amp., 3,000-kw., 4-section mercury arc rectifier with heat exchanger and at the right is a 750-amp., 9-volt plate-type copper oxide rectifier for electroplating service

years booster and split pole converters competed with the usual arguments as to which was the better. However, the advent in 1911 of commutating poles for synchronous converters put the split pole at a great disadvantage because of the resulting complications in design. From that time the synchronous booster with rotating booster armature in series with the main windings and the collector rings became the preferred unit for electrochemical and 3-wire lighting service.

The period from 1911 to 1930 may be regarded as the heyday of the synchronous converter as a conversion device. It is true that many motor generator sets were used because for some applications the ease and simplicity of d.c. voltage regulation of the MG set was preferred or because the d.c. voltage was 125 or less. However, superior efficiency of the synchronous converter gave it preference. Efficiency increased with the size of the units and therefore larger and larger units were applied. The largest units that have been used in electrochemical service are the four 16,000-amp. 340-volt units in the plant of the R & H Chemical Division of the DuPont Company at Niagara Falls. These units were not booster converters but shunt converters with load type tap changers for control of d.c. voltage.

During this period the most significant development in the conversion art was the introduction of fabricated design for machine parts. This development which had its inception in 1928 applied to both d.c. and a.c. machinery. It was an important influence because of the tendency it gave to reduction in cost and weight of the special machines which the electrochemical industry has always demanded.

As the synchronous converter approached its zenith, a new and quite different type of conversion device appeared on the horizon.

The steel tank mercury arc rectifier were imported from Europe shortly after the last war. In Europe its development had been promoted by the necessity for conserving copper during the war. It demanded exacting technique in manufacture and involved expensive research. These factors, as well as costly field troubles, made its initial progress very slow in this country and it was not until 1929 that it became a really commercial conversion unit. From that time on it rapidly replaced the synchronous converter in railway service. At about the same time the large metropolitan lighting systems began to change over from d.c. to a.c. and the business depression struck the country. The rise of the mercury arc rectifier then coincided with the decline of the synchronous converter. From 1930 on there has been an extremely rapid decline in the number of converters applied in the industry even though the adoption of the mercury arc rectifier for electrochemical service was delayed for several years.

Several causes led to the establishment of the mercury arc rectifier in traction service long before it was considered for electrochemical loads. One of these is the dependence of the rectifier efficiency on the voltage drop across the conducting arc of the rectifier; what is known as the "arc drop" of the rectifier. Approximately two-thirds of the entire loss of a conventional rectifier is dissipated in the arc drop, which in the rectifiers then available varied from 25 to 30 volts. As a result, the efficiency at 250 volts was considerably less than that of the synchronous converter, whereas at 600 volts which was standard in railway service, efficiency was very satisfactory.

The fact that a rectifier has better efficiency at light load than at full load was another advantage for traction service that has no meaning for the continuous maximum loads in electrochemical service. The ability of a rectifier to withstand high momentary overloads is a marked asset in railway work but is of no value in a cell load which does not fluctuate. Nevertheless, the chief obstacle to the adoption of the rectifier has been the comparatively low d.c. voltages used in the industry.

A rectifier is an ampere rated device although the transformer which goes with it is a kilowatt rated device. At 500 volts, a unit with an output of 1,000 kw. will consist of a 2,000-amp. rectifier and a transformer of sufficient kva. to give 1,000 kw. d.c. At 250 volts the rectifier is a 4,000-amp. unit and the transformer has the same rating. The lower voltage unit will therefore be more expensive per kw. of d.c. output.

These reasons and a well supplied market in used synchronous converters slowed up the introduction of the mercury arc rectifier except in special cases. For example, the earliest installation in North America for electrochemical service was made in 1929 at Traill, British Columbia, to supply d.c. at 650 volts for hydrogen and oxygen cells. The earliest rectifier in electrochemical service in the United States was not installed until 1934. Since then the increase in rectifier capacity has been remarkable. In 1937 comparative figures for the United States show—

- Installed rotating conversion units: 644,875 kw.
- Installed mercury arc rectifier units: 136,460 kw.
- Installed d.c. generators (turbine or diesel drive): 107,795 kw.

The estimated installed capacity in mercury arc rectifiers today is 150,000 kw. If equipment now on order but not yet installed is included, the capacity in rectifiers will be over

250,000 kw. These figures are for the United States alone and indicate the rapid increase in the use of this conversion device. In Canada there has been a similar rapid developmnt in rectifier applicatons.

In the same period, the increase in synchronous converter installations for this or any other industry requiring direct current has been almost negligible.

The mercury arc rectifier, meanwhile, was in process of further development, the results of which have greatly increased its value to the electrochemical industries. Because the arc-drop was the key to the effieiency of the rectifier, efforts were made to reduce it. These efforts culminated in the introduction by the Westinghouse Company in 1937 of the Ignitron rectifier, a type of mercury arc rectifier in which each anode and cathode is enclosed in an individual evacuated steel chamber. In this it differs from the earlier type of mercury arc rectifier often called the multi-anode type which has 6 or 12 anodes in a single evacuated chamber. While the multi-anode type is continuously excited, that is the exciting arc which gives rise to the so-called "cathode spot" on the surface of the mercury is always present in the evacuated chamber, in the Ignitron it is permitted to go out at the end of each conducting period and is renewed each cycle at the desired time.

By removing the exciting arc from the evacuated chamber at a time when the anode is carrying negative voltage there is no ionization in the speee between the anode and the cathode so the anode can be placed quite close to the cathode and the amount of shielding required can be made considerably less than with the multi-anode type. This results in much less arc drop for the Ignitron rectifier than for the multi-anode rectifier.

Because the arc is permitted to go out each cycle an external means of firing it is required. This is supplied by small thyratron tubes connected in series with the crystal starter across the anode and cathode of the Ignitron rectifier. The passage of current through the starter causes a high potential gradient at the surface of the mercury cathode into which it dips and produces the cathode spot. A very simple control of d.c. output voltage is then obtained by controlling the grids of these auxiliary firing tubes.

Continued research work has resulted in a decided improvement in the reliability of mercury arc rectifiers. In spite of what has been done, the mercury arc rectifier is still subject to the phenomenon known as "arc back." This means that occasionally the mechanism of arc retification is reversed and the cathode spot, which is essential to the operation of the device, for reasons that scientists have not yet been able to explain, suddenly appears on the anode at a time when it is carrying reversed voltage. An internal short circuit in the rectifier results which must be cleared by interruption of the circuit.

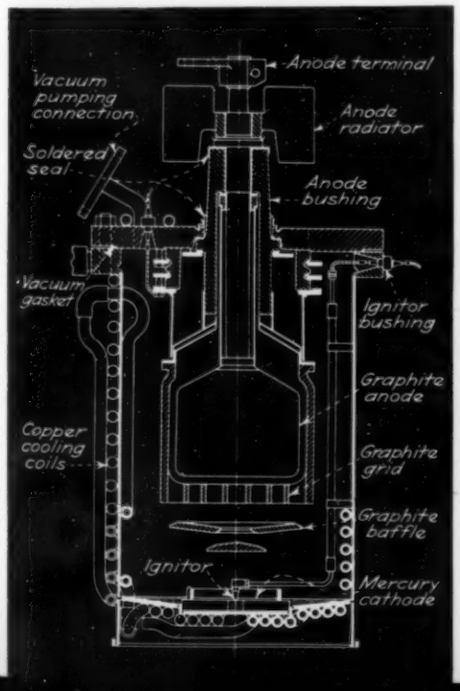
This momentary failure does not damage the rectifier in any way and it happens so rarely in a well designed and properly operated rectifier that it is neglected. However, efforts are being made to track down the causes of this phenomenon and when they have been found we may expect in time rectifiers entirely free from arc back. Furthermore, such rectifiers may be more efficient because our lack of knowledge of the cause of arc backs still makes it necessary to have more shielding and therefore greater arc drop than the ideal rectifier should require.

The progress of the Ignitron rectifier since its introduction in 1937 has been phenomenal. The first electrochemical installation went into service in 1938. This unit was rated at 4,800 amperes at 285 volts. Since then more than 17,000 kw. have been installed in traction, mining and other fields. The real proof of the success of this device is the fact that in the last few months a total of 280,000 amperes in Ignitrons have been ordered and will be installed before the end of this year. The increase in kilowatts from 17,000 to 180,000 in one year is impressive.

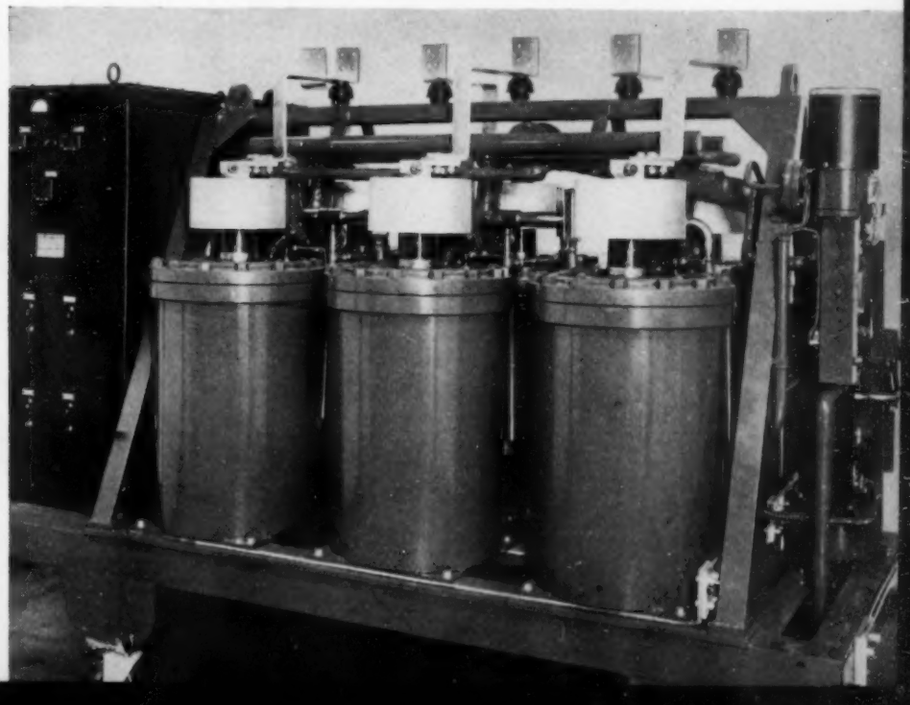
The fact that the Ignitron type of rectifier will be used in nearly all the recent large scale applications; by the Aluminum Company in its new plant in the Northwest, by the Canadian Aluminum Company as well as by the Dow Chemical Company in its new plant in the Southwest, is sufficient indication of its importance as a conversion device.

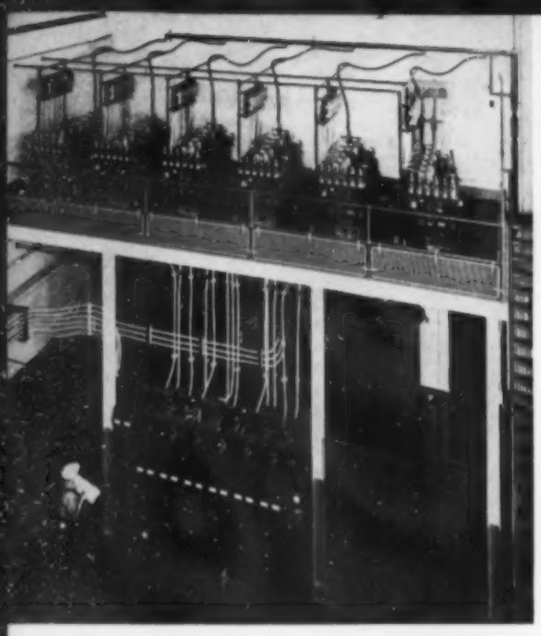
The question of rectifier vs. converter or motor generator set is still an open one as far as 250 volts is concerned, one reason being the availability of used 250-volt rotating equipment. As time goes on, the replacement problem will become more acute and the issue will be more sharply drawn. A long range plan will certainly favor the rectifier even if operating voltages can not be increased. For example, the building costs for a rectifier substation are less than with rotating equipment. No air

Cross-sectional view of an Ignitron rectifier showing details of construction



A six-cell Ignitron rectifier unit prior to installation; this unit gives 2,500 amps. at 600 volts. See chart on page 348 for efficiencies





Electrochemical plant installation of 4,800-amp., 285-volt Ignitron

Conversion Devices, Balance Sheet of Advantages and Disadvantages

Unit	Advantages	Disadvantages
Motor Generator Set	Voltage regulation simple and inexpensive, offers p.f. correction when synchronous drive is used. D.C. independent of a.c. Cost lower than rectifier at 250 volts.	Needs clean air for cooling. Overall efficiency comparatively low. Requires large starting kva. in some cases. Subject to current collecting problems. Heavy foundations. Noise. Cost of brushes.
Synchronous Converter	Comparatively high efficiency at 250 volts. Cost lower than rectifier at 250 volts. Operates at unity p.f., voltage regulation expensive.	Needs clean air for cooling. Subject to current collecting problems. Heavy foundations. Noise. Cost of brushes.
Mercury Arc Rectifier	Static device. Simple voltage regulation. Water cooled. Resists corrosion. Indefinite life, light weight compared to rotating equipment. Simple to operate. High efficiency.	Power factor below unity, depends on amount of grid control used. Initial cost at 250 volts higher than rotating equipment.
Copper Oxide Rectifier	Static device. Light weight. Indefinite life. Low maintenance.	Regulation not as good as with motor generator set. Slight loss in efficiency with age.

cleaning or special ventilation will be required.

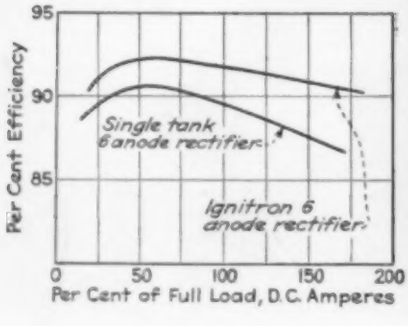
A different type, the copper oxide rectifier, has recently been tried out in the electrochemical industry. It had its start in the plating industry but it has recently found some useful application in electrolytic work.

It sometimes happens that the characteristics and performance of a new cell must be investigated under the proposed commercial operating conditions of current density, size of cell and so forth. It is not practical to do this with the normal power plant because even though the current is large the voltage is quite low, being from four to six volts.

The d.c. required can be obtained very conveniently and economically from a copper oxide rectifier which has grown in the last few years from a small control or battery charging device to a real power supply. Its advantages are simplicity in construction and operation; it has no moving parts except a small ventilating fan and no maintenance to speak of. Its application is limited to the low voltage field because it is not economical to build them for large currents and voltages in excess of 12 volts. They are commercially competitive with the special motor generator sets which are used for plating power supply.

Forty-five years of the conversion art brings us to the present. The rise and decline of the synchronous converter has been noted. The rapid use of the mercury arc rectifier is shown. No attempt will be made to prophesy, as improvements are always to be expected. However, it is very unlikely that the conversion device of the future will be a piece of rotating equipment. Long life and low maintenance always accompany the static electrical device. The conversion unit will be no exception to this general rule.

Comparative efficiencies of 600-kw., 275-volt, voltage controlled multi-anode single tank and Ignitron rectifiers



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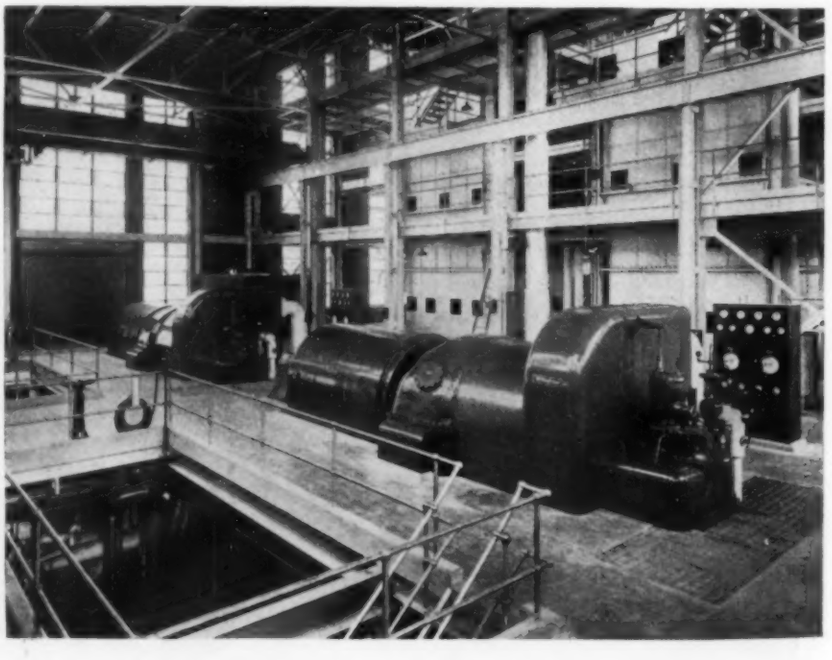
Not a conversion device, the photograph below shows the two new 9,378 kva. turbine generators in the E. I. duPont Company's Nylon plant at Seaford, Del.

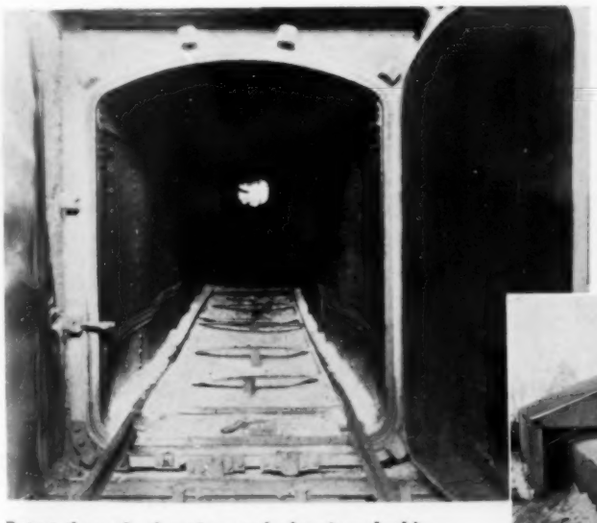


Acetic Acid from Wood Distillation

ACETIC ACID, direct from wood distillation, is still an important material and competitive with synthetic acetic acid. Among more recent chemical engineering contributions is the Othmer process which *Chem. & Met. Eng.* (Vol. 42, page 356) described in detail, although since 1935 various improvements and economies of operation have been made. Charcoal and methanol of various grades are, of course, also produced. In modern processing, hard wood, preferably beech, birch, or maple is air dried for a year and then fed into predryers where the moisture content is reduced from about 50 per cent to 25 per cent, then carbonized out of contact with air, cooled for two days in successive coolers; and the charcoal so produced is graded, sized, and packaged.

The vapors are condensed in the condensers adjacent to the retorts and non-condensable gases are used for fuel either under the boilers or under the retorts. Tar is always present or formed and must be removed at several points. The methanol is distilled off and refined. Water is removed from the acetic acid (discharge is pure, contains only .01 per cent acid) by an azeotropic distillation using a water insoluble solvent as the entrainer; and the acid remaining is separated from the tarry impuri-

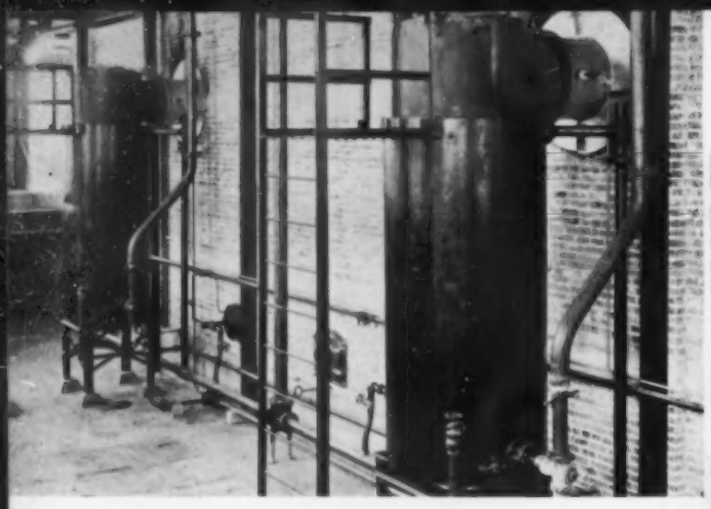
ties and refined to give as pure a product as may be made by any synthetic process. Another product from American hard wood charcoal, a high grade of activated carbon, is also shown as it is produced by the Gray company as an important contribution to the fields where activated carbon has become an essential. The following photographs illustrate wood distillation and the Othmer process as conducted at the Gray Chemical Co., Roulette, Pa. Some of the pictures are also by courtesy of Vulcan Copper & Supply Co. of Cincinnati and Crossett Chemical Co., Crossett, Ark.



Retort through charging end showing double doors, track for buggies and condenser outlet

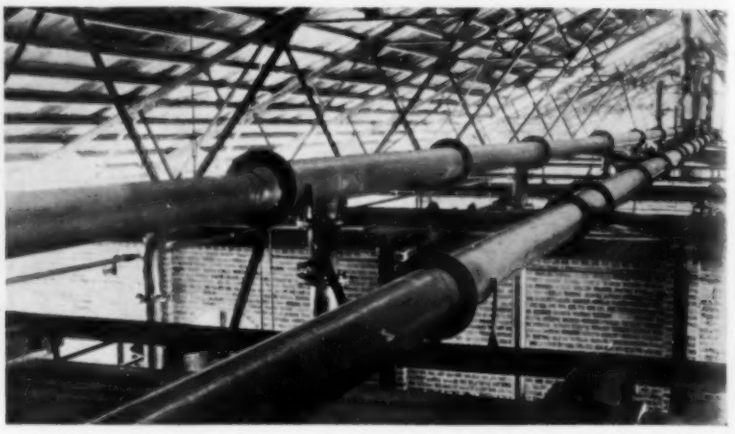
A Chem & Met PICTURED FLOW SHEET

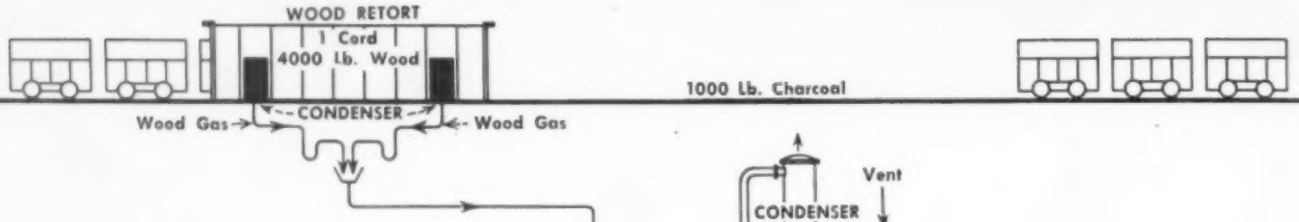
Charcoal in buggies on way to second coolers. Natural cooling is necessary to prevent fire and eliminate spontaneous combustion



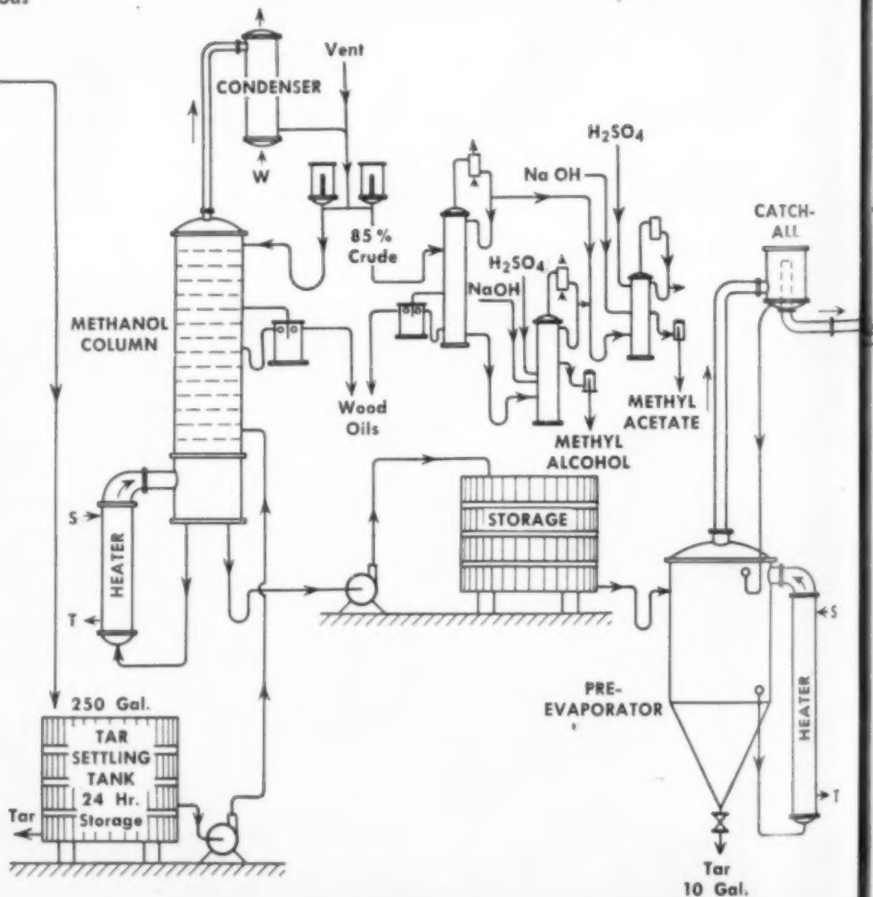
Retort condensers showing outlet from the spill funnel for pyroligneous acid to storage tanks, and the non-condensable gas lines

Wood gas header to water scrubber for volatiles. Upper header is washed gas line for burning under retorts

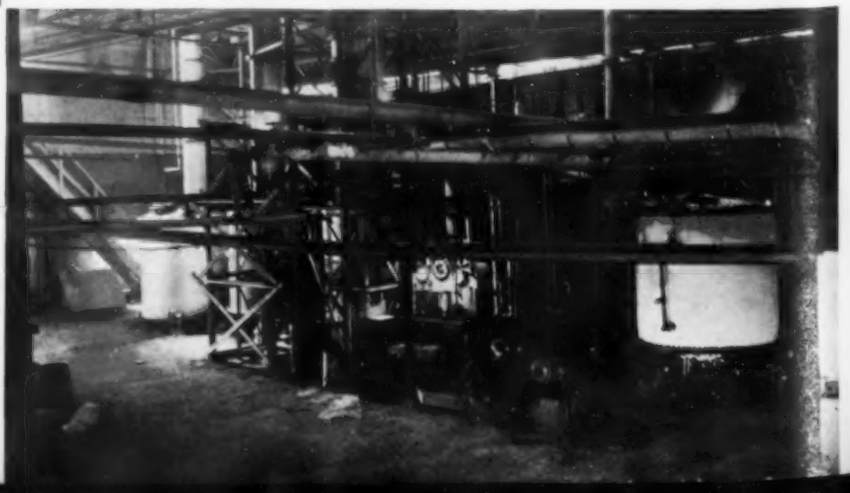




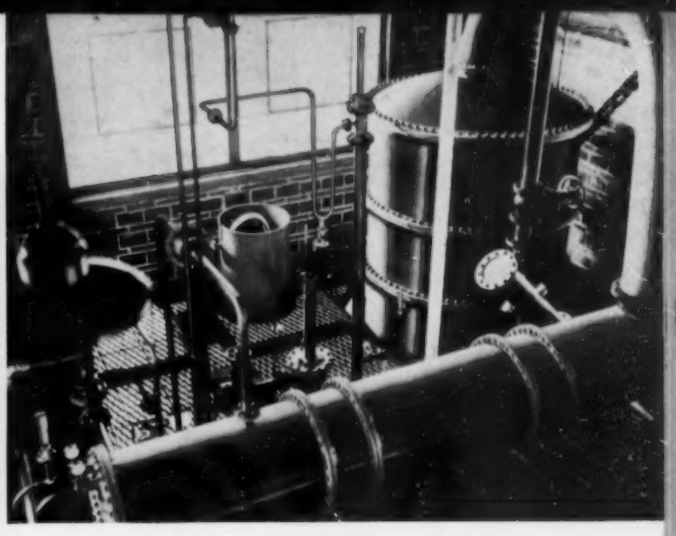
Tubs, used for 40 years, setting insoluble tars from pyroligneous liquor inflowing from tank to tank (total settling time 24 hours)



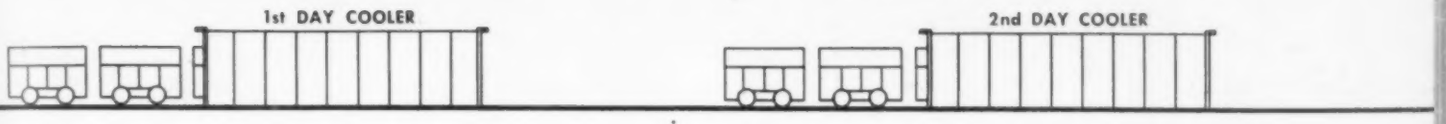
Demethanolizing unit and methanol refining unit, far left; control panel with gages and meters for demethanolizing column, above and to left; feed and water pumps, below and to left.

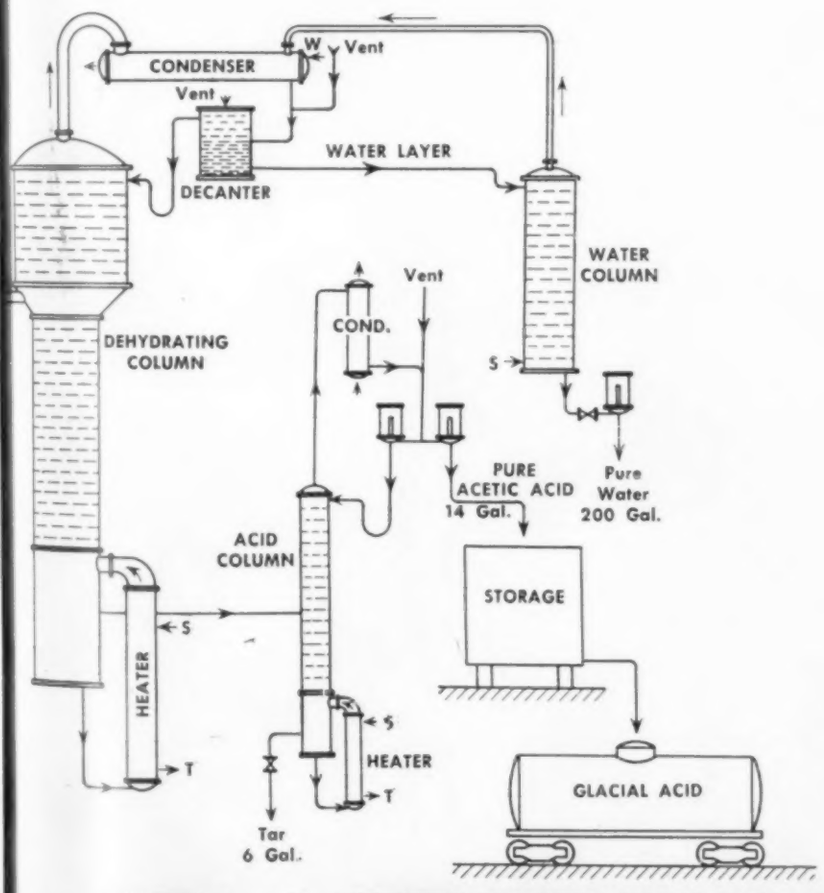


Charcoal in buggies leaving retort on right, entering first cooler on left. The turn-table arrangement is shown

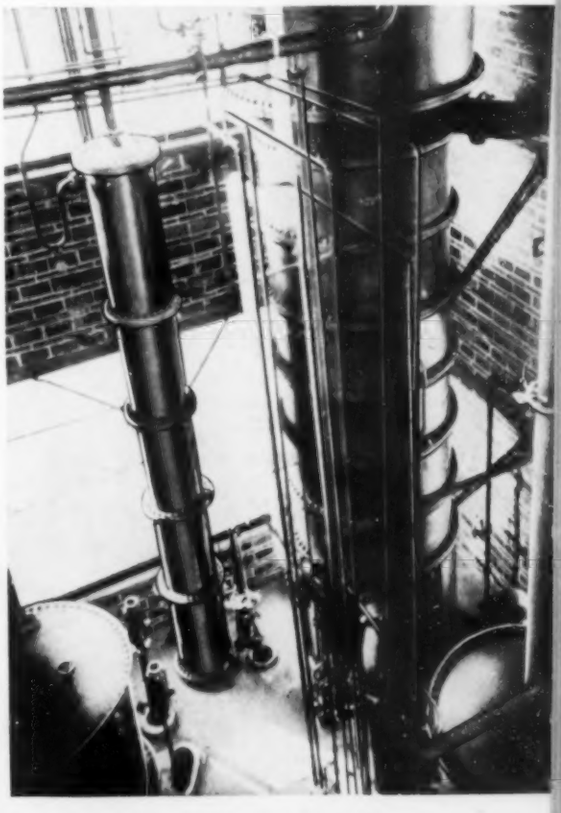


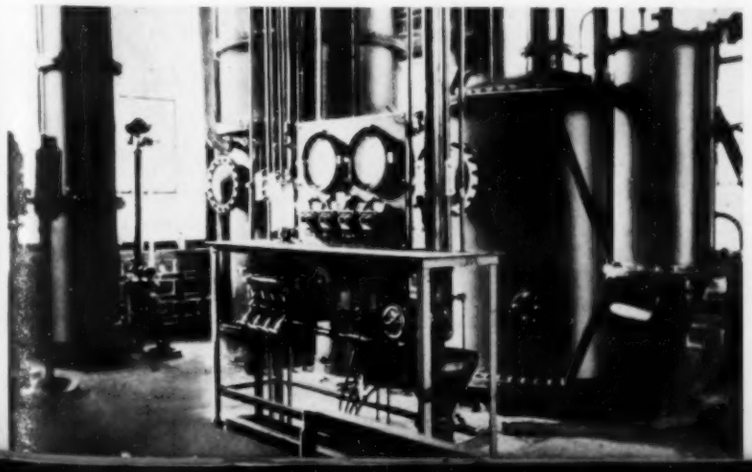
Acid refinery: top of dehydrating column, main condenser, silver condenser for final acid in background





Acid refinery: dehydrating column in the center, a pre-evaporator on lower right and acid refining column on left

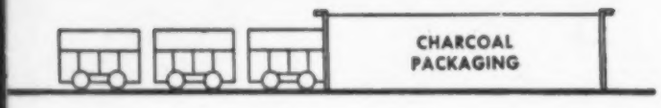


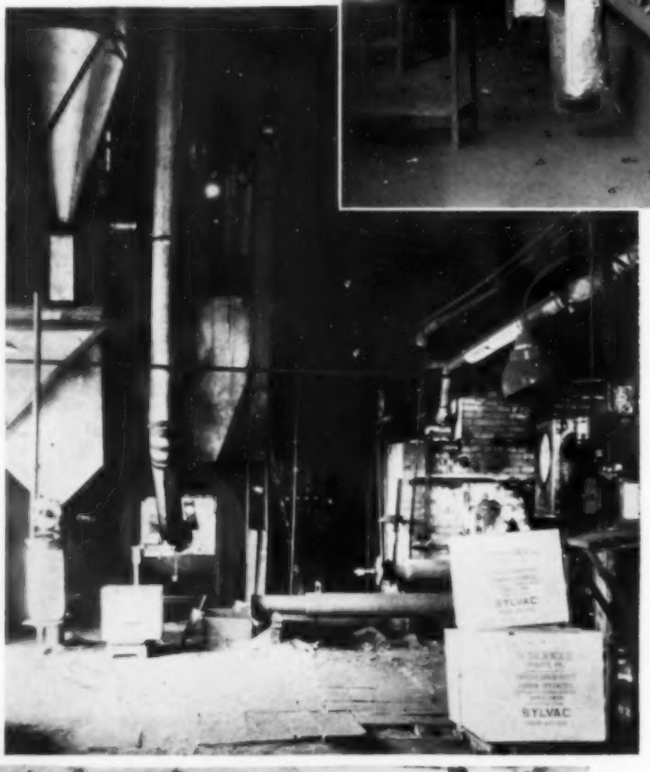


Operating floor of acetic refinery. Pre-evaporator on right distills to main column removing water. Acid refining column on left

Charcoal is unloaded from the rack in tipple house and passed through grizzly bars on right. Any uncompletely carbonized pieces of wood are removed at this point

Lump charcoal is dropped into hopper shown by means of a belt conveyor and as it works down dust is allowed to flow through screen bottom





Charcoal is activated in tube at a high temperature, is fed to hopper over continuous Raymond mill equipped with dust collecting and sizing classifier. It is discharged in sacks and packed

Airplane view of the plant of the Gray Chemical Co. at Roulette, Pa. in which many of these photographs were taken

New Electrochemical Developments

EDITORIAL STAFF REPORT

F. C. Mathers of University of Indiana elected Society president

Colin G. Fink again reelected secretary of Electrochemical Society

THE 77TH MEETING of the Electrochemical Society was held at Wernersville, Pa., April 24-27. This meeting-place proved to be a popular choice for an unusually large number of members and guests were attracted to the Pennsylvania resort located in the neighborhood of many interesting industrial plants.

Dr. Frank C. Mathers was elected president of the Society. He hails from the University of Indiana which he serves as professor of inorganic chemistry. The newly elected vice-presidents are: E. M. Baker of the University of Michigan; G. B. Hogaboom, Sr., of Hanson, Van Winkle, Munning Co., and M. de K. Thompson of the Massachusetts Institute of Technology. The new managers are: S. D. Kirkpatrick, editor of *Chemical & Metallurgical Engineering*, A. K. Graham of A. Kenneth Graham & Associates, and R. L. Seabury of Delco-Remy Corporation. R. M. Burns of the Bell Telephone Laboratories and Colin G. Fink of Columbia University were re-elected treasurer and secretary respectively.

The Society awarded the twelfth Weston fellowship of $1,000 to Waldemar P. Ruemmler of St. Louis. He will continue his research at Columbia University, investigating the electrodeposition of antimony. The work will be done under the direction of Professor Fink.

The Society's prize to young authors was awarded to Dr. George A. Moore of Princeton, N. J., for his paper entitled "The Comportment of the Palladium-Hydrogen System Toward Alternating Electric Current." Dr. Moore is instructor in metallurgy at Princeton University.

Technical sessions were held on the following subjects: (1) Electric steel; (2) Electrodeposition of copper and other metals; (3) Galvanic effects and other electrochemical phenomena; (4) Electrolytic oxidation and reduction, and (5) Fundamental subjects.

The session on electric steel was presided over by Dr. P. H. Brace of Westinghouse Electric & Mfg. Co. The present status of the electric arc furnace in industry was discussed by W. E. Moore, president of the Pittsburgh company bearing his name. He stated that in the ingot field the modern top-charge rapid-type electric furnaces are in competition with the open hearth furnace for producing ordinary carbon steels of the commercial grade. In the production of tool steels, stainless and other alloy steels, the electric arc furnace is distinctly superior. Carbon electrodes have been markedly improved in quality of material as in the joint fitting and finishing. They have been greatly improved as to the electrical conductivity by means of couplings. The graphite electrode has likewise been improved in texture and particularly in fitting and finish of the joint. Carbon blocks are now available for use as refractories and linings, for electric furnaces and have a useful place in smelting furnaces for ferro-alloys, carbide, phosphates, etc. They are obtainable in many shapes at prices that are competitive considering their desirable quality. Fused mullite refractories promise to be used more extensively in arc furnaces. Radical changes have been made in electric arc furnace designs. Details of the development of the modern hot-charge furnace were discussed. The new "lift-swing-aside" roofs are very smooth and rapid in operation. Data for a 12-ton furnace were given.

Stainless steel rolled products were discussed by P. B. Greenawald, the Carpenter Steel Co., Reading, Pa. The commercial success of stainless steel is due primarily to the electric furnace and the ability to keep the carbon content of the alloy down to 0.10 per cent. The working of stainless steel was difficult at first but marked improvement in composition and heat treatment have been

made so that today the stainless steels are worked very much like carbon steels. The machining of stainless steels was likewise difficult at first, but the addition of small percentages of sulphur or selenium to the alloy has solved the problem. The surface of stainless steel can be made mirror-bright, practically matching chromium plate.

Some new developments in corrosion resistant steel were discussed by George F. Landgraf of the Lebanon Steel Foundry, Lebanon, Pa.

It has been found possible to make silver additions to the 18-8 steels sufficiently large to improve directly the pit corrosion resistance on the theory of the formation of the relatively insoluble silver chloride. However, the silver does not actually form an alloy with the 18-8 but is held in suspension in minute, evenly dispersed particles throughout the molten alloy bath. One of the very real and at present definitely provable advantages of the silver inclusion is a tremendous increase in the machinability as well as the forgibility of the 18-8 alloy to which the silver has been added. The author concludes that there are certain applications which this silver bearing material will satisfactorily fulfill that could not previously be met with a comparable material.

ELECTRODEPOSITION OF METALS

The session concerned with the electrodeposition of metals was under the supervision of Dr. William Blum, National Bureau of Standards, Washington, D. C. Developments in the commercial electrodeposition of cobalt-nickel alloys during the past two years were described by Louis Weisberg, chemical consultant of New York City. Improvement in method of removing impurities has made it possible to reduce the cobalt content of the deposit for some purposes, as low as 1 per cent. Substitution of nickel formate and formic acid for sodium formate and use of less ammonium sulphate have resulted in deposits that are more ductile and easier to buff than those formerly obtained. The excellent physical properties of cobalt-nickel alloy deposits are brought out in striking fashion when thick deposits are applied. Smooth sound deposits can be produced at unusually high current densities and there have been some interesting applications based on this fact.

The relative amount of stress in deposits of copper made at different temperatures and current densities was determined by the measurement of the elongation of the spots on a Debye-Scherrer transmission X-ray film relative to their width by Elbert M. Mahla of Lehigh University. Stress was plotted against current density and temperature in a 3-dimensional diagram. In deposits made at low temperatures, temperature was shown to be a greater factor than current density in determining the stress, while at high temperatures current density was the principal factor. No direct relationship between hardness and stress were observed by the author.

The cathode and anode polarization values of copper in sodium cuprocyanide solutions of various concentrations have been determined by J. V. Petrocelli, the Patent Button Co., Waterbury, Conn.

Single nickel deposition of copper, cadmium, zinc and nickel from thiosulphate solutions was the subject of a paper by D. C. Gernes of the Tennessee Valley Authority, Florence, Ala., G. A. Lorenz, Shell Petroleum Corp., Wood River, Ill., and G. H. Montillon, University of Minnesota, Minneapolis. They presented results of an investigation to determine the possibilities of thiosulphate baths for single metal deposition and to determine the behavior of these baths during deposition. It was believed that the investigation of any complex salt which might be useful in deposition would be of both theoretical and practical value in this field.

Progress in electrolytic refining of metals with special reference to the last decade was discussed by Max F. W. Heberlein of the U. S. Metals Refining Co., Carteret, N. J. The review indicates that throughout the world development work on copper and the precious metals have been predominating. This is partly due to the fact that these metals are economically and commercially more important than others. On the other hand, the electrolytic method is the only efficient refining method for copper and the precious metals, whereas fire refining methods for other metals are more economical in many cases.

Galvanic effects and other electrochemical phenomena were the subject of a session presided over by Dr. Hiram S. Lukens of the University of Pennsylvania. Professor Fink of Columbia University and Johnstone S. Mackay, now with Catalytic Development Co., Marcus Hook, Pa., described an investigation comprising a study of photocell materials. The principal development is a new photo element using bismuth sulphide as the photo active material. The characteristics of this cell was studied and it was found that a laboratory-prepared bismuth sulphide cell has 80 per cent of its activity in the infra-red range of the spectrum, gives 5 microamperes per lumen and has a threshhold wave length of approximately 7.0 microns. The bismuth sulphide cell is applicable as the basis of temperature control in low temperature systems.

OXIDATION AND REDUCTION

The session on electrolytic oxidation and reduction was under the supervision of Dr. H. Jermain Creighton of Swarthmore College. Prof. Sherlock Swann, Jr., of the University of Illinois discussed electroorganic chemical separations. This review was an extension of an earlier list of electroorganic syntheses which should be of value as methods of preparation to include literature published before January, 1940.

The electrochemical oxidation of n-hexanol was the subject of a paper by William Robert Lowstuter and Prof. Alexander Lowy of the University of Pittsburgh. n-Hexanol was oxidized electrochemically, giving n-caproic acid and n-hexyl caproate. Besides these main products, small amounts of carbon dioxide, carbon monoxide and a high boiling residue were obtained. Hexaldehyde and decane were not found to be present in the products of the electrolysis. A study was made of the various factors influencing the oxidation, such as anode material, temperature, current density, solvent and alcohol concentration of the anolyte for the electrolytic oxidation of n-hexanol. The best results were obtained under the following conditions: (a) 5 per cent sulphuric acid as electrolyte; (b) current density, 1.1 amp./dm.^{2}; (c) temperature, 12 deg. C.; (d) electrolytically prepared lead dioxide anode; (e) anolyte concentration, 82 G. n-hexanol in 800 cc. of electrolyte; current efficiency, 59.9 per cent calculated only as oxidation to caproic acid.

A brief review of the various directions in which oxidation-reduction potential measurements have been applied in recent years was given by Samuel Glasstone, Frick Chemical Laboratories, Princeton, N. J. Some measurements are of importance not only to the chemist, but also to the biologist. Among the applications discussed by the author are potentiometric titrations, indicators for biological reactions and irreversible potentials.

Machinery, Materials and Products

Chem & Met Process Equipment NEWS

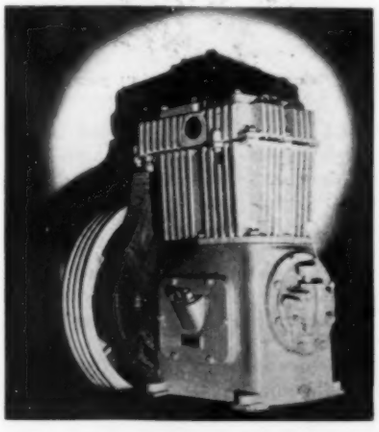
Industrial Compressor

Two NEW pressure-lubricated air compressors intended particularly for heavy duty industrial use have been announced by the Quincy Compressor Co., Quincy, Ill. Model 244 is a duplex-cylinder, single-stage compressor with a maximum piston displacement of 45.7 c.f.m. Model 340 is a two-stage compressor having 40 c.f.m. maximum displacement. Lubrication in both types is furnished by a gear pump supplying oil to connecting rod bearings and pistons. Anti-friction main bearings are splash-lubricated. Deep vertical fins on the cylinders are provided for cooling in combination with a flywheel fan. A copper-finned intercooler is supplied with the two-stage model.

Flange Jack

AN ACCOMPANYING ILLUSTRATION shows the use of the new "Flange-Jacks" recently announced by the Garlock Packing Co., Palmyra, N. Y. This new tool, designed for replacing gaskets in flanged pipe lines, is said to eliminate wedging and hammering of flanges as well as broken flanges and damaged flange faces. The jacks are used in pairs, the jaws being inserted in the flange holes and the flanges forced apart by tightening the pointed jack screws. Three sizes are available for flanges under 2 in., flanges from 2 to 20 in. and flanges from 14 to 48 in.

Two-stage pressure lubricated air compressor

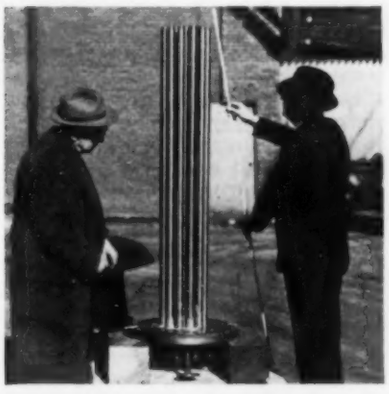


Opening flanged joint with Flange-Jacks

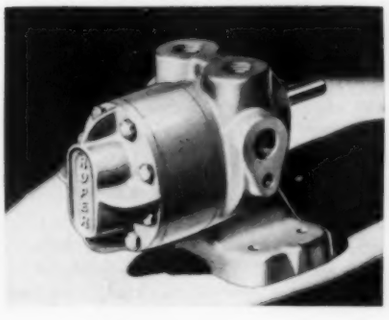
Tantalum Heater

A RECENT ANNOUNCEMENT of the Fansteel Metallurgical Corp., North Chicago, Ill., describes a new multiple-bayonet type heater for the evaporation of muriatic acid. The new heater employs 19 tantalum bayonet heater elements, similar to the single bayonet formerly available. Each tantalum tube contains a steel inner tube which conducts steam to the top of the heater. Steam and condensate flow downward, heating the inner surface of the tantalum tube through which heat is transferred to the acid. The unit is designed to operate at 150 lb. steam pressure. Owing to the extremely high heat transfer obtainable through the thin-walled tantalum tubes, this small unit is capable of evaporating 5 tons of muriatic acid per hour, according to the manufacturers. The unit shown was designed to be fitted into the bottom nozzle of a glass-lined evaporating vessel. Greater economy is claimed than with a conventional shell and tube heat exchange.

Multiple-tube tantalum bayonet heater



New rotary pump



Rotary Pump

A NEW LINE of rotary pumps recently announced by the Geo. D. Roper Corp., Rockford, Ill., includes 16 different capacities ranging from 1 to 1,000 g.p.m. at speeds up to 1,800 r.p.m. and against pressures up to 1,000 lb. per sq.in. At present 21 different drives and mountings are available with arrangements for direct motor drive, gear reduction, flat or V-belt drive. The line contains over 7,000 different units. An outstanding feature, according to the manufacturer, is the utilization of a means of obtaining hydraulic balance to equalize internal pressure at all points and absorb shock or thrust from the power end of the drive shaft. Spiral, spur or herringbone gears may be had, with various packing and seal methods, various types of bearings and eight different piping arrangements.

Equipment Briefs

A NEW electronic switch designed to prevent arcing and welding of contacts, for use with thermostats, limit switches and other devices requiring low contact pressure or limited movement, has been announced by the United Cinephone Corp., 43-37 Rawson St., Long Island City, N. Y., Through the use of a vacuum tube, the new switch requires only 1 micro amp. across the primary contacts, yet provides a relay contact capacity of 3 amp. at 110 volts, a.c. This result is obtained through use of the valve action of the vacuum tube.

FOR THE making of duplicate copies of line drawings in quantity, the A. B. Dick Co., Chicago, Ill., has introduced a new photo-chemical printer by means of which any opaque drawing on translucent cloth or paper can be transferred to a sensitized stencil sheet. The stencil is then developed and placed in a mimeograph duplicator for the making of accurate black and

white reproductions in quantity. The time from finished tracing to finished copy is said to be generally less than 25 min. and the cost of materials for producing a stencil less than 25 cents on the average.

A NEW special gage for oxygen service at high pressure has been announced by the American Gauge Div., Manning, Maxwell & Moore, Inc., Bridgeport, Conn. Beryllium copper is used for the bourdon tube. The gage cover is of transparent plastic. Accuracy is guaranteed to be within one-half of 1 per cent.

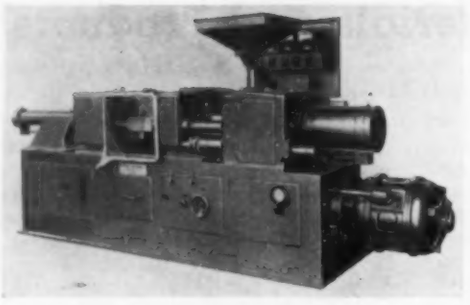
WARREN LAMP Co., Warren, Pa., has announced a new line of inside-silver-plated incandescent lamps in sizes from 75 to 300 watts, for industrial use. Placing the reflecting surface inside the glass bulb eliminates reflector maintenance as well as the use of separate reflectors. According to the manufacturer, the new lamps give double the light of a standard lamp of the same wattage, give greater light concentration through the use of a specially designed parabolic shaped bulb, and have longer life.

Injection Molding Press

AN IMPROVED hydraulic injection molding machine for plastics, designed for faster operation, increased capacity and economies in operation and maintenance, has been announced under the designation of No. 8-A by the Watson-Stillman Co., Roselle, N. J. A distinctive feature is the zone heat control which is said to provide well-distributed heat, giving a greater plasticizing capacity to the heating cylinder. The exceptionally large opening between die plates allows for the accommodation of dies 6 in. thick, and more. Dies up to 125 sq.in. projected area can be accommodated. Two material cylinders are available for this machine, one injecting up to 6 oz. at 50,000 lb. per sq.in. and the other up to 8 oz. at 32,000 lb. per sq.in. Controls provide for full automatic, automatic and manual control. Working pressure is 2,050 lb. per sq.in.

Special Blender

AN ACCOMPANYING VIEW shows a blender for viscous liquids which was recently designed with a number of unusual features by L. O. Koven & Bro., Jersey City, N. J. The blender is of stainless clad steel, motor driven and provided with a stainless steel double-spiral agitator. A pair of semi-circular racks are mounted on a superstructure on which barrels or drums can be placed for drainage into the tank and rocked on wheels to remove all of the contents. This arrangement is stated to facilitate control of the rate of addition of the liquid being poured into the blender. This type of blender is also recommended by the manufacturer for the handling of syrups, emulsions, creams, pastes and for the mixing of dry or semi-wet solids with liquids.



New model 8-A injection molding machine

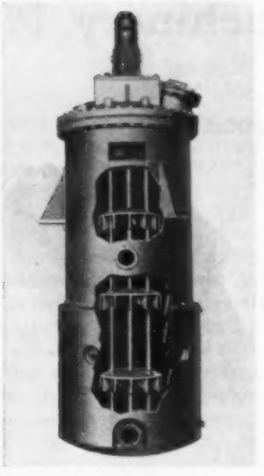
Stainless steel blender

Proportioning Pumps

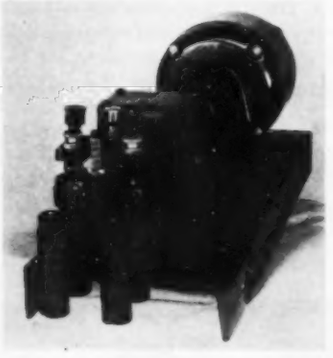
MODEL SA is the designation of a new type of chemical proportioning pump which has recently been announced by the Hills-McCanna Co., 2349 Nelson St., Chicago, Ill. This pump, the smallest one produced by the company, has a number of novel features. The unit consists of two liquid cylinders, a drive mechanism, speed reducer, motor and base. The liquid ends incorporate a unique design of pump body and check valve in which both suction and discharge valves are incorporated in the one check valve body. The pump body is of the outside packed deep stuffing box type. Discharge adjustment is secured by operating the plungers at constant speed and varying the stroke of each plunger individually as desired.

Gas Absorber

FOR THE HANDLING of a variety of gas absorbing problems, the Patterson Foundry & Machine Co., East Liverpool, Ohio, has developed a new line of gas absorbers available in plain and stainless steel as well as in a variety of non-ferrous metals. The accompanying cutaway view indicates the construction of a stainless steel absorber 3 ft. in diameter and 7 ft. high, designed for 60 lb. internal pressure and 100 lb. jacket pressure, fitted with three 12-in. gas-absorber turbine agitators.



New gas absorber



Miniature proportioning pump

"Valv-Amp" Rotor

A NEW DEVELOPMENT in rotor construction is being employed by the General Electric Co., Schenectady, N. Y., in the manufacture of cast-aluminum rotors for the larger sizes of double-squirrel-cage motors for high-starting - torque, low - starting - current service. Called the "Valv-Amp" rotor, it makes use of a unique shape of rotor slot and a special method of assembling rotor punchings to control the flow of starting current. As a result, without the use of a switch or other moving parts, current is permitted to flow in the outer squirrel-cage when the motor is started, thus producing high starting torque. Then when the motor comes up to speed, current is allowed to flow through the entire assembly of rotor bars, resulting in good running characteristics.

It is claimed that previously it has not been practicable to cast double-squirrel-cage rotors in the larger sizes. The new development, therefore, for the first time in larger cast-rotor motors, combines the advantages of the double-squirrel-cage construction with the simplicity of conventional cast-rotor design.

Welded Fittings

NEW FABRICATED and welded fittings, made in copper and Everdur, in a wide range of sizes and types, have been announced by the American Brass Co., 25 Broadway, New York, N. Y. The new fittings range in size from 8 to 24 in. and are available in the form of 45- and 90-deg. elbows, reducers, straight tees, reduction-on-run tees, reduction-on-branch tees, crosses, laterals, flanges, and special fittings made to specification. Everdur fittings are said to offer tensile strength comparable to mild steel of the same gage. The new fittings are intended particularly for chemical plant, paper mill and petroleum refinery use.

Fluid Impact Mill

A NEW TYPE of mill designed for disintegrative treatment of all types of fluid mixtures has been announced by Asbury Research Developments, Wyncote, Pa. The new mill employs specially designed rotors to produce impact by means of centrifugal force. These rotors, operated in successive stages, divide the liquid into a fine mist, the particles of which are driven by centrifugal action against impact rings designed to direct the fluid film so formed into the periphery of the succeeding rotor. Since mechanical contact does not take place, grinding action is avoided and heating is said to be minimized. Without the use of cooling mechanism, it is claimed that no mixture yet processed in these mills has shown a temperature rise of more than 2 deg. C. during passage. Another consequence of the lack of frictional contact is that adjustments are unnecessary and the temperature of material processed is claimed to have no effect on the operation of the mill.

Among the suggested applications are the production of emulsions of mineral and vegetable oils, asphalt emulsions, the dispersion of pigments, clays and fillers, the manufacture of paints, enamels and ink. Any material which will flow or can be pumped can be processed, according to the manufacturers.

Fluid impact mill

Vernier control on P.I.V. Gear

Vernier Speed Control

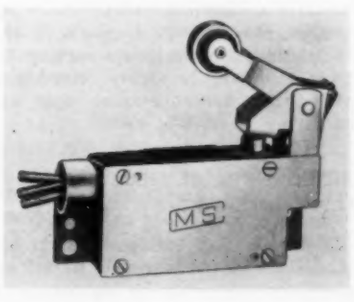
A RECENT ANNOUNCEMENT by the Link-Belt Co., 2045 West Hunting Park Ave., Philadelphia, Pa., describes a new vernier speed control for the Link-Belt P.I.V. Gear variable speed transmission. This device is equipped with two hand-wheels, one for direct control and the other for vernier control, the latter providing either 30 turns or 7½ turns, depending on the fineness of adjustment required, for one turn of the direct wheel. The manufacturers recommend the new control for all applications where particularly fine sensitivity is required, as in the synchronizing of speed of two machines, justifying for shrinkage in paper, controlling feeders and weighers, and similar applications.

Air Eliminator

A NEW automatic valve for the removal of air from steam-heated retorts, paper machines, creosoting cylinders and on-and-off steam mains has been developed by the Armstrong Machine Works, 858 Maple St., Three Rivers, Mich. The unit consists of a conventional diaphragm valve to which is added a dome-shaped inlet chamber containing a bellows thermal expansion unit operating a needle valve. This valve acts as a pilot to admit pressure to the top of the diaphragm. The diaphragm is vented when the pilot valve is closed.

When air enters the inlet the thermal element cools, and opens the needle valve, in turn applying pressure to the diaphragm, opening the main valve and permitting the air to escape. When steam enters the valve, however, the pilot and in turn the main valve closes. A wide range of sensitivity adjustment is provided.

Cam actuated switch



New Micro Switches

MICRO SWITCH CORP., Freeport, Ill., announces the development of two new Micro switches for ratings up to ½ hp. and voltages up to 460 a.c. One type is a water-, oil- and dust-tight construction, employing a die-cast metal housing and a molded neoprene seal surrounding the plunger mechanism. The other type, designated as LK-2, is a precision limit switch for actuation by rotating or sliding cams, having a roller actuator adjustable through an arc of 225 deg. This new switch has a movement differential at the roller of 0.002 in., a pretravel of 1 deg., an over-travel of 20 deg. and an operating pressure of less than 1.8 lb.

Braidless Insulated Wire

A NEW DESIGN of rubber-insulated cable protected with a bonded sheath made of neoprene has been announced under the name of Okoprene by the Okonite Co., Passaic, N. J. A feature of the new construction is that braids and saturants are not used in the cover. The new sheath is claimed to seal the insulation from air and light and prevent deterioration of the rubber. Such cables are said to resist moisture, oils and chemicals and also to be flame-resistant. In the case of high voltage cables, the Okoprene cover has the additional advantages of being unaffected by ozone and of having a high surface resistance lessening the danger of damage from static discharge. The new construction is recommended by the manufacturer for voltages up to 5,000, for practically all locations where ordinary rubber-covered wire has previously been installed.

Refrigeration Compressor

THROUGH ITS Carbondale Division, Worthington Pump & Machinery Corp., Harrison, N. J., is offering a new eight-cylinder, V-type refrigeration compressor available in capacities from 75 to 125 tons for single units, and up to 250 tons with duplex arrangement. The new compressors are intended for use with Freon-12. Important features include sturdy construction, light weight and compactness, providing large capacity where headroom is limited. Either V-belt or direct motor drive can be used with either a horizontal shell-and-tube condenser mounted on the unit, or without the condenser for using this company's shower type condenser. Air conditioning of medium large buildings is the recommended field of the compressor.

BUREAU OF LABOR DEVISES NEW PRICE INDEX FOR CHEMICALS

After several years of intermittent effort the Bureau of Labor Statistics has evolved a new chemical price index. The new index is based on quotations for a list of commodities which was selected with the assistance of Manufacturing Chemists Association. The result appears to be a great improvement over any previous Government effort. In order to make the new figures significant, the Bureau of Labor Statistics has recalculated monthly indexes back to the beginning of 1933, using standard quotations for the new commodities list. And annual averages are available as far back as 1926 which is the year used as a base for the index.

Those requiring further details regarding the formulation of the index and the old price calculations should request a copy of the March, 1940 issue of "Average Wholesale Prices and Index Numbers of Individual Commodities," as issued by the Bureau of Labor Statistics in Washington.

In making up this chemical price index the Bureau has segregated in other groups comparable data on drugs and pharmaceuticals, fertilizer materials, mixed fertilizers, and oils and fats. Then a general composite is made called "Chemicals and Allied Products" from these four and the chemicals index.

MANUFACTURING CHEMISTS WILL MEET AT SKYTOP

The sixty-eighth annual meeting of the Manufacturing Chemists' Association will be held at Skytop Lodge, Skytop, Pa., on June 6 and 7. The business session will open at 10 o'clock on the morning of June 6 with Lammot du Pont, president of the Association, in charge. J. Anton de Haas, Professor of International Relationships, Harvard Graduate School of Business Administration will address the members on the subject "The Problems of Economic Adjustment from the European War." James S. Thomas, president of the Chrysler Engineering Corp., will discuss the contributions of industry to the development of modern civilization, taking as his subject "Culture and the Market Place."

As has been the case in recent years, the Manufacturing Chemists' Association will act as host to the members of the Synthetic Organic Chemical Manufacturers Association at the union dinner which will be held on the evening of June 6. The guest and speaker at the dinner will be Harold G. Moulton, president of Brookings Institution who will take as his topic "Is Further Capital Expansion Possible?"

ARMOUR INSTITUTE WILL GIVE SUMMER GRADUATE COURSES

Armour Institute of Technology, Chicago, will conduct a three-term Summer Graduate Institute for engineers, professional men, industrials, and educators in engineering and science beginning next summer. The first term will extend from June 17 to July 13; the second term from July 15 to Aug. 10; and the third from Aug. 12 to Sept. 7.

The chemical engineering and chemistry division for the first term will be given over to chemical engineering thermodynamics under the direction of Barnett F. Dodge, professor of chemical engineering and chairman of the chemical engineering department of Yale University, and to general catalysis under the direction of Vasili I. Komarewsky, research professor of chemistry at Armour Institute of Technology. The program for the second term includes interpretation of chemical engineering data under the guidance of C. C. Furnas, associate professor of chemical engineering at Yale, and industrial catalysis with J. C. Morrell, associate director of research, Universal Oil Products Co., as the lecturer. The third and final term will be devoted to advanced chemical engineering plant design directed by Frank C. Vilbrandt, head of the department of chemical engineering at Virginia Polytechnic Institute, and to designing equipment for applications of chemical engineering with Harry McCormack, professor of chemical engineering at Armour in charge.

POWER SHOW SCHEDULED FOR FIRST WEEK OF DECEMBER

The 14th National Exposition of Power & Mechanical Engineering has recently been announced for Dec. 2-7, at Grand Central Palace, New York. Better known as the National Power Show, this biennial exposition brings together the product displays of over 300 leading manufacturers serving the power field, and is widely attended by power engineers, operating men and executives.

FRICTION WILL BE DISCUSSED AT M.I.T. CONFERENCE

Engineers, oil technologists, and manufacturers from many fields will hold a conference at the Massachusetts Institute of Technology on June 5-7, with friction and surface finish as the main topic to be discussed. At the morning session on June 5, Prof. Jerome C. Hunsaker of M.I.T. will preside and the afternoon meeting will be in charge of D. A. Wallace of the Chrysler Corp. The sessions on June 6 will be directed by M. Olley of Rolls Royce, Inc. and Haakon Styri of S.K.F. Laboratories. Discussion on the final day will be opened by L. M. Tichvinsky of the Westinghouse Research Laboratories and H. G. Mougey of General Motors Research Laboratories will act as chairman.

ATLANTIC REFINING CO. HONORED ON 70TH BIRTHDAY

At the Franklin Institute in Philadelphia, nearly 400 oil men, chemical engineers, and editors gathered on April 29 to pay tribute to the Atlantic Refining Co. for 70 years of pioneer work in petroleum research. Mr. Robert H. Colley, president of that company, accepted from Dr. Henry Butler Allen, secretary and director of the Institute, a citation setting forth outstanding accomplishments of the company. Some of these were pioneer work in the following fields: tower stills, modern pipe stills, solvent extraction and thermal production of motor fuels.

Results of Atlantic's most recent research project, the Florida Road Test, were disclosed by Dr. T. G. Delbridge, manager of the research and development division, in his address "Dollars and Miles." With colored movies and slides he gave evidence to support his startling contention that 1940 low-priced automobiles can travel as many miles per gallon at 100,000 miles as at 10,000 miles with modern gasoline. Other equally surprising results of the company's 4-month road tests were described.

Thomas A. Boyd, director of fuel laboratories, General Motors Corp., also took part in the celebration. In his talk "Carriages Without Horses Shall Go," he outlined the rise of the petroleum industry during the past 70 years and pointed out the parallel rise in the automobile industry. Stressing inter-dependence of these two industries he said, "From the place they occupy in his budget the automobile user has about the same interest in gasoline and oil as in the car itself. This is so because during the lifetime of his car he pays just about as much for the gasoline and oil he buys as he did for the car in the first place." Mr. Boyd further pointed out that the number of research workers in the petroleum industry had increased from 150 in 1920 to 5,000 in 1938; the money spent for research from $500,000 to $20,000,000 in the same period. Gasoline yields from crude oil have risen from 25 to 45 per cent. Retail prices have dropped from 32 to 15 cents per gallon (ex-tax).

Philip C. Staples, president of The Franklin Institute and of the Bell Telephone Co. of Pennsylvania, presided.

NEWS FROM WASHINGTON

Washington News Bureau
McGraw-Hill Publishing Co.
Paul Wooton, Chief

PROCESS industry is not only enmeshed in domestic politics of Washington, but is also seriously concerned with international policy and plans of the Capital City. The chemical engineer, willingly or otherwise, must therefore now make decisions that should be purely economic or technologic, while he has at all times an eye on these political and international factors. There seems to be no escape from this unfortunate fact.

Since 1940 is a Presidential election year, the complications are aggravated. And the threat of a third-term movement prevailing at the Democratic convention does not in any sense simplify the problems. Industry executives and engineers must realize that under such circumstances there is no ground for expecting reasoned and fact-founded decisions by either the executive departments or the members of Congress.

Food and Drug Moves

In the fourth Executive Order contemplating reorganization of the government services, the President transferred Food and Drug Administration from the Department of Agriculture to become an independent bureau in Federal Security Agency. All of the personnel, appropriations, problems, records, and authority of F. & D. A. go together. The authority formerly exercised by the Secretary of Agriculture will be held by the Administrator of F.S.A. when the transfer has been perfected.

Under the law this transfer cannot take effect until after notice is before Congress for sixty days, which period expires June 11. This provision gives Congress opportunity to veto the proposed changes by enactment of an appropriate bill. Although there has been some criticism of the transfer of aeronautic activities from C.A.A. as an independent agency to the Department of Commerce, there seems little likelihood that any of the changes suggested by the President will be vetoed by Congress.

So far as the transfer of Food and Drug activities is concerned, the chemical industry probably will be very little affected. As one Washington observer put it, the change does not mean any more than the naming of a new Secretary of Agriculture might have meant.

New Far East Problem

No one knows how far Uncle Sam could be dragged into a controversy with Japan over Netherland Indies questions. But the statement by Secretary Hull, promptly confirmed by the President, made a point which Japan will recognize clearly. This country will not hesitate to use all of its economic force if necessary to protect these Dutch possessions from Japanese interference if Holland should suffer military difficulty at home and be unable to defend its colonies.

Numerous units of process industry are deeply concerned with this situation. That colonial area is one of the world's major sources of rubber and tin. Very important exports of minerals come from that area also, including bauxite, monazite, and some of the minor strategic minerals. It would be a very great burden on many units of industry in the United States if Japan should undertake to exploit those resources either by raising the price to American processors or by trying to do the processing in the Orient and thus cutting off present manufacturing opportunities.

Naval gestures may be made, but Washington does not expect a real military movement even if the worst comes to pass. Commercial interpreters do not think force would be necessary. The United States still has a long leverage in trade relations with the Mikado's subjects. Even the military clique would probably not wish to venture the full threat of economic strangulation that the United States could exert on raw materials or other business factors of Japan. Fear of that effort will probably deter any over-ambitious Japanese from reaching greedily for the Dutch colonies under present circumstances. But forecasting on this subject must be limited to the near future.

Secondary effects of elaborate change in the balance of power in Europe might produce strange results. Meantime, Washington is pleased to know that synthetic rubber of various types is being commercially developed in the United States. And many official observers ask, "Why can't we do without much of the present tin by substituting lacquer or other chemical equivalents?"

News "Fines"

More Trade Pacts—Perhaps the most significant feature of the legislative battle which extended the authority for trade agreement negotiation another three years is the outside interpretation given. Responsible interpreters claim that the President had to "buy two Senators." That such a charge is openly made without stirring prompt refutation, fairly well pictures the low level to which Washington seems to have sunk lately.

Mines Bureau Changes—Dr. R. R. Sayers, of the Public Health Service, has been named as Acting Director of the Bureau of Mines. For fifteen years he was chief of the health and safety work of that Bureau, but more recently has been active in P.H.S. work. Several groups of chemical industry are well acquainted with Dr. Sayers because of his important participation in voluntary agreements regarding methanol marketing, ethyl-fluid manufacturing precautions, and other similar industrial safety efforts.

James W. Furness, who has been chief of the Economics Branch, has found it necessary to retire from his post because of health disability. J. H. Hedges, who was formerly assistant director, has been transferred to a minor mining engineering post at College Park, Maryland. It is not anticipated that Dr. Sayers as acting director will soon name permanent successors for either of these two high posts within the Bureau.

New Truck Rules — The Interstate Commerce Commission has promulgated new regulations governing transportation of explosives and other dangerous articles by motor vehicle. These are similar to, though not identical with, regulations for the transportation of these materials by rail. Those interested in obtaining a set of these motor carrier safety regulations will find them printed in full in the Federal Register of April 23. They apply to both common carrier and contract carrier whenever "engaged in the transportation in interstate or foreign commerce of any explosive or other dangerous article in or on any motor vehicle."

Fertilizer Materials — Washington hears generally from the fertilizer industry that there is no shortage of any important fertilizer chemicals. Even potassium sulphate is reaching the industry in adequate quantities for all formulas that really require that component. A few mixers in Eastern and New England states are substituting other potash compounds, especially where the material is marketed for other crops than tobacco. There is a little uneasiness that early next Fall there again may be minor shortages of this material as there will then be no large reserve stocks on hand as there were at the outbreak of the European conflict last September. But production plans are being made which will make the shortage a minor, rather than a major, difficulty, producers confidently forecast.

Legislation—Congress is struggling mightily to finish enactment of the railway legislation, long in conference; and there is some chance that stream pollution control under Public Health Service may also be provided. The President and Congressional leaders are struggling to get Congress out of Washington very early in June so that

the Chief Executive can make a transcontinental speaking tour while the Republican convention is on at Philadelphia. This makes it smart politics for Republicans and anti-third-termers to adopt dilatory tactics. Many folks think that adjournment just before the Republican convention is the earliest that can be expected.

Walter-Logan Bill—Even the most optimistic conservatives were amazed that the House passed the Walter-Logan bill by a vote of 3 to 1, much more than enough to override a Presidential veto, which some say would meet this measure at the White House. The Senate is much less enthusiastic for the idea of offering opportunity for court review of all executive agency proceedings. But they hold their noses just as tight as do House members when they get near the N.L.R.B. mess. The President's strength in the Senate appears to be sufficient to prevent overriding a veto, or perhaps enough to prevent this bill from coming up for a vote at all.

Washington expects that in 1941 some such measure will be enacted because Congress feels that under Supreme Court decisions of recent date there is real need of opportunity for aggrieved persons to get into the courts. The decision last week that the courts cannot review findings of N.L.R.B., whether capricious, unreasonable, or founded on fact, strongly impresses even the progressive members of Congress.

A.I.Ch.E. MAKES AWARDS IN STUDENT PROBLEM CONTEST

Howard Campbell, senior chemical engineering student at McGill University, Montreal, was the recipient of the A. McLaren White Award of $100 at the 32nd semi-annual meeting of the American Institute of Chemical Engineers in Buffalo on May 13. In presenting the award Dean Webster N. Jones, president of the Institute, stated that it is made annually to the student submitting the most satisfactory solution to a chemical engineering problem prepared by an Institute committee.

Second and third prizes of $50 and $25 respectively went to Wilmer L. Kranich of the University of Pennsylvania and Leroy N. Chellis of Clarkson College, Potsdam, N. Y. O. R. McIntire of the University of Kansas was awarded honorable mention and a $10 prize.

McGill, the only University outside the United States to have a student chapter of A.I.Ch.E., produced a contest winner for the first time in the nine years since the origin of the award. This year there were, according to Dean Jones, 56 solutions submitted to the judges from 34 of the Institute's 69 student chapters—an all time high. Several hundred students worked on the problem but failed to submit acceptable solutions.

Administration of the problem contest is conducted by the Institute through its Committee on Student Chapters. This year the problem was prepared and judged by a sub-committee headed by Dr. William T. Nichols, director of research, Westvaco Chlorine Products Corp., South Charleston, W. Va. The problem involved the design of a plant for extraction and distillation of acetic acid.

CHEMICALS AND EQUIPMENT WILL BE EXHIBITED AT BRESLAU

A Congress-Show on "Materials and Chemistry" will be held on the occasion of the National Meeting of the German Chemists by the DECHEMA, German Association of Chemical Equipment Manufacturers, of the National Socialist Alliance of German Engineering from July 28 to August 4, 1940 in Breslau in the Exhibition buildings in that city.

The aim of the Congress-Show is to display the numerous materials for the chemical engineering equipment industry, particular consideration being given to recently developed materials and to promote systematic united work in this field and all questions connected therewith, such as selection, application, treating and testing. At the same time there will be shown chemical and scientific apparatus and instruments which are new in importance.

RECORD SHIPMENTS OF ALUMINUM SALTS LAST YEAR

Domestic shipments of aluminum salts last year exceeded those for the previous peak year of 1937 by 6 per cent according to figures issued by the Bureau of Mines. The tonnage shipped was reported at 494,032 tons with a value of $11,813,299 which compares with 412,905 tons and a value of $10,197,354 for 1938, hence the gain over 1938 was 20 per cent in quantity and 16 per cent in value. Aluminum sulphate accounted for the greater part of the shipments with 443,029 tons passing to consumers which necessitated a drawing upon stocks as total production for the year was but 438,692 tons. As there were but two producers of soda alum, data for that product have been combined with that for sodium aluminate with shipments reported at 24,153 tons for 1938 and 31,252 tons for 1939. All the other products enumerated, including ammonia and potash alum and aluminum chloride, were shipped in larger volume last year.

COMMERCE DEPARTMENT SUBMITS CHANGES FOR POTASH INDUSTRY

The Department of Commerce after several months of study of the potash industry, undertaken at the request of the anti-trust division of the Department of Justice, has submitted its report which recommends three major changes in the present conduct of this business:

Establishment of a price differential of approximately $7 per ton between the price at Carlsbad, N. M., one of the two important sources of domestic production, and the price at the seaboard. At the present time, prices at Carlsbad and at the seaboard are identical.

Establishment of a multiple discount system, in place of the present single discount, to encourage purchase of potash by fertilizer mixers in advance of their requirements, smooth the rate of delivery to mixers and discourage cancellation.

Modification of sales policy so as to permit consumers to purchase direct from producers in carload lots for their own use at regular quoted prices with the usual discount.

ELECTROCHEMISTS WILL HEAR DR. NORTON AT WORLD'S FAIR

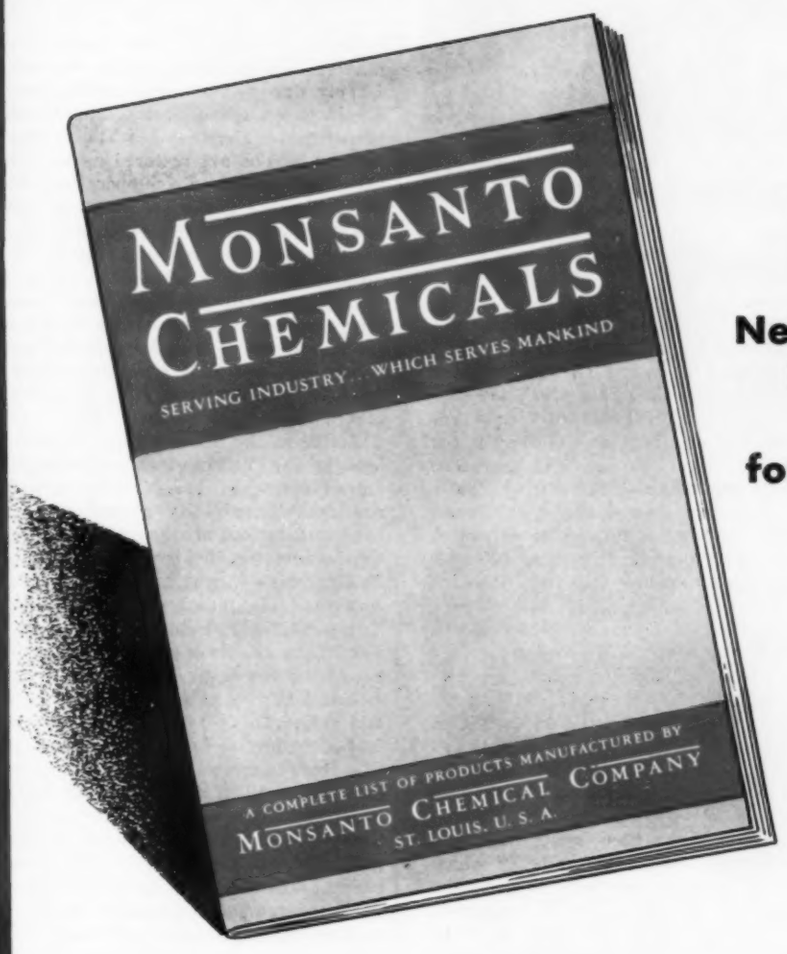
Dr. Francis J. Norton, prominent research chemist and physicist, will be the chief speaker May 25 at "Electrochemical Society Day" at the World's Fair of 1940 in New York. More than 1,000 members and guests of the metropolitan section of the Electrochemical Society will attend a luncheon and special program at the Gas Exhibits building. Dr. Norton of the General Electric Research Laboratory, Schenectady, will discuss "Polarized Light and the Electrical Properties of Colloids", presenting new facts discovered regarding clay in the colloidal form. These new phenomena will be spectacularly demonstrated by the use of polarized light.

POTASH COMPANY OF AMERICA TO PRODUCE CAUSTIC AND CHLORATE

Potash Company of America, with executive offices, mines and refinery at Carlsbad, N. Mex., and general sales offices in Baltimore, has completed arrangements for the production of potassium chlorate and potassium hydroxide.

Shipments of Aluminum Salts

	1938		1939	
	Tons	Value	Tons	Value
Alum				
Ammonia	4,079	$218,019	5,570	$294,866
Potash	2,085	121,174	2,709	156,358
Aluminum chloride				
Liquid	2,174	99,208	3,121	136,792
Crystal and Anhydrous	6,166	521,492	8,351	830,347
Aluminum sulphate				
Commercial				
General	349,051	7,345,471	408,324	8,031,897
Municipal	10,689	161,160	11,010	166,590
Iron free	14,508	417,446	23,695	587,573
Sodium aluminum sulphate and sodium aluminate	24,153	1,313,384	31,252	1,608,876



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New Monsanto Product Booklet lists over 300 Chemicals for American Industry

The 1940 edition of the Monsanto Product List is available to all members of the chemical process industries. The products listed to the right are only a few of the Monsanto Chemicals described in this new booklet, copy of which will be sent on request. Address your inquiries to any Monsanto office. MONSANTO CHEMICAL COMPANY, St. Louis, U. S. A. District Offices: New York, Chicago, Boston, Detroit, Charlotte, Birmingham, Los Angeles, San Francisco, Montreal, London.

Monsanto Products for the Chemical Process Industries

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- Alcohol
- Aluminum Sulfate
- Ammonia, Aqua
- Amyl Acetate
- ortho-Anisidine
- Butyl Acetate
- Calcium Pyrophosphate
- Caustic Soda
- Chlorine
- meta-Cresol
- ortho-Cresol
- para-Cresol
- Cresylic Acid
- Diacetone Alcohol
- Dinitrochlorbenzene
- Ethyl Acetate
- Mersol (Solvent)
- Methyl Salicylate
- Mixed Acid
- Monochlorbenzene
- Monsanto Salt
- Muriatic Acid
- Nitric Acid
- ortho-Nitroaniline
- para-Nitroaniline
- ortho-Nitroanisole
- Nitrocellulose Solution
- ortho-Nitrochlorbenzene
- para-Nitrochlorbenzene
- para-Phenetidin
- Phenol
- Phosphoric Acid
- Phosphorus Oxychloride
- Phosphorus Trichloride
- Phthalic Anhydride
- Piperidine
- Pyridine
- Salicylic Acid
- Salicylic Acid (Technical)
- Salt Cake
- Sodium Aluminate
- Sodium Bisulfite
- Sodium Pyrophosphate (Tetra)
- Sodium Sulfite
- Solvents
- Sulfuric Acid
- Sulfuryl Chloride
- Tricresyl Phosphate
- para-Toluenesulfonamide
- para-Toluenesulfone Chloride
- Wetting Agents

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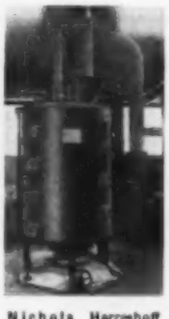

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ABILITY OF GERMANY TO SECURE IRON ORE HAS ECONOMIC AND MILITARY IMPORTANCE

From Our German Correspondent

MUCH discussed are the relative assets and liabilities for the German Reich in case of successful German occupation of Scandinavia. In the economic sphere the acquisition of additional Scandinavian food resources is counterbalanced by the necessity of providing other food and fodder imports to keep Scandinavian economy on an even keel.

Although military factors were apparently more important than economic, Swedish iron ore, some of which is exported by way of Norway in winter months when Swedish ports are icebound, undoubtedly is an important consideration. With Germany's ore supplies from France and northern Africa cut off, and those from Spain, Luxembourg, Jugoslavia, and Greece becoming more uncertain, the Swedish ores figure prominently in the Reich's industrial plans. In 1938 Sweden and Norway supplied 10 million tons, or one-half of Germany's ore imports. Even if the Atlantic Norwegian iron ore port of Narvik comes into complete British control, there is still an alternative rail route open to the Reich from Sweden by way of Denmark, as well as the Baltic Sea route from the Swedish port of Lulea on the Gulf of Bothnia.

Germany has been using about 33 million tons of ore annually, of which only 11 million tons were supplied domestically in 1938. This German ore, however, averaged less than half the iron content of the Swedish ore, which runs 65 to 70 per cent. The use of scrap iron explains the difference between the Reich's steel ingot production figures of 23.3 million tons and the pig iron output of only 18.5 million tons in 1938. A reserve of scrap iron of 10 million tons is considered to be available in the Reich in the form of old iron, steel rails, old railroad engines, etc. It is also estimated that in spite of the increased demand for war materials, domestic iron requirements could be reduced by as much as 30 per cent as in the World War. Such a reduction would be facilitated by the fact that light metals, plastics, glass, etc. have been used in the past few years to replace iron and steel wherever possible. Some experts feel that even if Germany were completely cut off from Scandinavian ores, she could still carry on the war.

In addition to the domestic ores being mined in the Old Reich and Austria, Germany is planning exploitation of deposits in Polish Upper Silesia and in Bohemia-Moravia. These are relatively small deposits of low grade ores, varying in iron content from 20 to 40 per cent. Some of the mines had been abandoned in past years because of high production costs. In fact, the early reluctance of large concerns to develop low grade domestic ores was largely due to fears that such plants would be an economic loss and would probably be abandoned when normal trade relations are restored again. In the meantime, the Reich-operated Hermann Goering works are claiming that the cost of producing from domestic ore one ton of Thomas pig iron can be reduced to 52 RM and that of one ton of rolled iron to 85 RM. This would compare favorably with the costs of one Ruhr plant which calculated 42 RM per ton in 1936 and 50 RM per ton in July, 1939 to produce iron from imported ores.

Active in the utilization of domestic ores is the Vereinigte Stahlwerke in Düsseldorf, which has recently received considerable publicity abroad due to the confiscation of the properties of the leading stockholder Fritz Thyssen. As Germany's largest coal and iron concern and in number of employees Europe's largest industrial enterprise, Vereinigte Stahlwerke's recently published balance sheet is of interest; 202 million RM were paid out in taxes alone last year. This represented the equivalent of 44 per cent of the capital stock. The concern nevertheless paid a 6 per cent dividend. Although balance sheets have never given much clue to any German concern's operations, it appears, as was expected, that the processing branches of the Vereinigte Stahlwerke proved more profitable than the coal and iron producing divisions last year.

The effect of the war on the automobile industry, with overseas markets cut off and domestic automobile traffic curtailed in order to save motor fuel has been reflected in several reorganizations and changes in models. At the Vienna spring trade fair, new cars exhibited all stressed smaller cylinder capacities. Generally, few changes were made as compared with last year's models. The Ford V-8, for example, which is manufactured in the German plant at Cologne, exhibited more or less the same models, but cut down the motor from a 3.6 liter capacity to 2.2 liters. The Austrian firm Steyr-Daimler-Puch and the automobile division of the Czech Skoda works exhibited jointly, since the two firms have now merged their sales organizations. The number of models shown was greatly reduced in line with the general policy of cutting down the number of types of cars to effect manufacturing efficiencies and to save raw materials. A novelty at the Vienna fair was a Hans Trippel combination land and water automobile. The car, which looks a great deal like the German racing cars, is claimed to run 65 miles per hour on land, to be able to climb 70 per cent grades, and to be able to make good speed in water with the aid of a triple bladed pro-

peller. Its four-cylinder engine has a 2 liter cylinder capacity and develops 46 hp. at 4,000 revolutions.

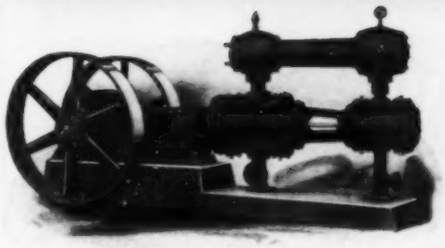
The degree of motorization in Germany is still relatively low, however, when it is realized that in the five years from 1933 to 1938 the number of motor vehicles increased by only one and a half million, which was double the number in use in 1933. The automobile has lagged behind the train and ship as a commercial carrier in Europe in the past, due to lack of adequate roads, because of the relatively shorter distances to be traveled, and partly because of the high cost of motor fuels and taxes on automobiles. Partly for strategic reasons and partly to connect industrial areas with the rest of the Reich, construction of the new express highways has been pushed in recent years so that more than 2,000 miles of these new roads are now in use.

With the death of Dr. Carl Bosch, head of I. G. Farben, on April 26 at the age of 65 in Heidelberg, Germany lost its leading figure in the chemical industry. Professor Bosch, who was awarded the Nobel prize for chemistry in 1931 is best known for his work in developing synthetic gasoline, synthetic ammonia, and other substitute products. His encouragement of research and commercial application of new processes have been largely responsible for building up I. G. Farbenindustrie's worldwide reputation.

Dr. Bosch was also president of the Kaiser Wilhelm Society for the Promotion of Science. Established in 1911 by Emperor Wilhelm to correlate the study of natural sciences, at present the Society maintains 36 institutions with a staff of about 2,000, of whom 811 are scientists. These institutes, located in different parts of Germany and Austria (the Research Station for Microbiology, working on leprosy, is located in Sao Paolo, Brazil), are divided into three main groups, the first covering physics and chemistry and their technical applications, the second biology and medicine, and the third the moral sciences. The Society sponsored 1133 scientific publications last year, maintains close contact with foreign scientific institutes, and encourages foreign scientists to study in Germany, and provides a central club building in the Harnack House at Berlin-Dahlem. In this connection it is of interest that of the 2,000 foreign students enrolled at the 24 German colleges and universities open during the winter semester 1939-40, 529 studied at the Institute of Technology at Berlin-Charlottenburg. The majority of these students are from southeastern Europe and Scandinavia.

The lack of overseas oils and fats has greatly stimulated in the Danubian basin the planting of oil-producing plants, including rapeseed, flax, hemp, castor, gourds, poppy, sunflower, and soybeans. The climate of southeastern Europe is favorable to raising oleaginous plants, and the Balkan govern-

Are your compressors in step with the new chemical processes



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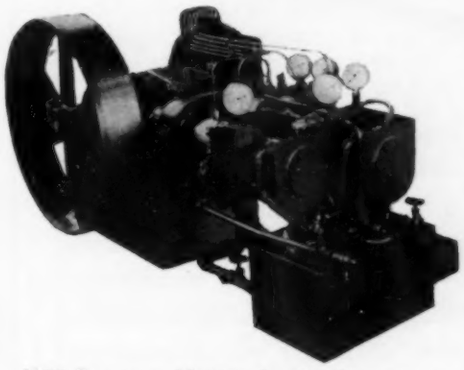

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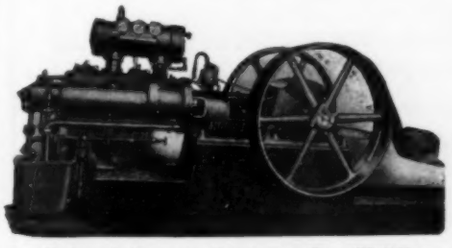

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ments are pushing the idea to get away from monoculture of grains. This has been especially true since attractive prices have been offered since the war has cut off importations from overseas. Production is still subject to considerable fluctuations, however. Rumania is the leading soybean grower in the Balkans, having boosted its output from 10,770 metric tons in 1935 to 76,000 tons in 1939, most of this being exported to Germany. With new uses constantly being developed for soybeans in the chemical laboratories, this product promises to become an important raw material in the Reich even after the war is over.

Among new products being developed in the Reich are novelty shoes made entirely of "Plexiglass," shatter-proof glass produced from an organic base. Plexiglass has already been extensively used in addition to furnishing light weight airplane glass, for making buttons and other notions. Shoes of the material are claimed to have hard plexiglass heels and uppers as soft and pliable as leather. Plexiglass and plastics are finding increased uses in the Reich, especially since techniques for welding the materials have been improved.

The German optical industry has announced an improved type of magnifying glass, combining "visolette" glass, which illuminates the magnified object by concentrating light upon it, and an amplifier lens.

CRUDE TURPENTINE USED FOR MOTOR FUEL IN SWEDEN

A report from our commercial attache at Stockholm says that a well-known Swedish motor expert has recently discovered the use of crude turpentine as a motor fuel. By placing a copper plate having a hole of smaller diameter than the cylinder in the connection between the cylinder top and the motor block, the turpentine becomes atomized. The heat of the copper also aids in this procedure. So far, the method has been developed only for the use of motors having top intake valves. It is also necessary to devise some method for cooling the copper gasket. Such studies must be made for each individual motor and heretofore methods have been devised only for the Hanomag automobiles.

HYDRAULIC INSTITUTE SPONSORS ESSAY AWARD

In order to stimulate interest of the younger men in the industry, the Hydraulic Institute of New York is offering cash awards to writers of essays dealing with problems which arise in the pump industry. Any employee of member companies is eligible to compete except executives, heads of departments and those holding managerial or policy-making positions. The prizes will be awarded and the winning essays read at the annual meeting of the Institute to be held in December.

LALOR FOUNDATION ANNOUNCES WINNERS OF AWARDS

The Board of Trustees of the Lalor Foundation has announced the names of winners of seven awards for research in chemistry for the academic year 1940–41.

The recipients of the awards are: Dr. Andrew Calvin Bratton, Instructor in Pharmacology at Johns Hopkins University Medical School, to continue work with Dr. E. K. Marshall on chemical aspects of chemotherapy of compounds of the sulfanilamide type; Dr. Robert Byron Jacobs of the Research Laboratory of Physical Chemistry of the Massachusetts Institute of Technology, to continue work with Dr. F. G. Keyes on fundamental properties of materials at low temperatures; Dr. Joseph O. Hirschfelder, Research Associate at the University of Wisconsin, to work with Dr. Linus Pauling of California Institute of Technology in an investigation of the best ways and means for calculating the quantum mechanical energy of molecules; Dr. Jane Anne Russell of the University of California to continue biochemical investigations under Dr. C. N. H. Long at Yale University; Dr. Robert N. Simha from the University of Vienna to work with Prof. V. K. LaMer at Columbia University on the statistical problems and kinetics of polymerization in long chain compounds; Dr. E. L. Robert Stokstad, Biochemist, Western Condensing Co., Berkeley, Calif., to work with Prof. H. Borsook at California Institute of Technology on vitamin factor U and an unknown factor in polished rice; and Dr. Robert P. Walton, Professor of Pharmacology, University of Mississippi, for chemical and clinical work at the University of Chicago.

A.S.T.M. WILL HOLD ANNUAL MEETING IN ATLANTIC CITY

In order to provide ample time for the presentation and discussion of the large number of technical papers and reports to be presented at the forty-third annual meeting of the American Society for Testing Materials to be held at Chalfonte-Haddon Hill, Atlantic City, N. J., June 24-28, twenty-two separate sessions are being arranged, with several symposia and certain groups of technical papers indicating a strong technical program which covers a field broad enough to arouse widespread interest.

Of interest to the field of chemistry and chemical engineering will be the Symposium on Tools of Analytical Chemistry covering two complete sessions of the meeting. This is being arranged with the cooperation of the Division of Physical and Inorganic Chemistry of the American Chemical Society, the program having been developed by Dr. G. Frederick Smith, Professor of Chemistry, University of Illinois, and Dr. G. E. F. Lundell, Chief, Chemistry Division, National Bureau of Standards.

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PERSONALITIES

Bruce K. Brown

C. M. Hoff

✦ GEORGE C. MILLER has been appointed sales manager of the Plastics Division, Carbide & Carbon Chemicals Corp. He has been associated with the division activities since his early commercial development of Vinylite resins.

✦ OTTO HENSE has been appointed to the newly created position of sales manager of the Pigment Division of Eagle-Picher Sales Co. He has been eastern representative of the division for several years.

✦ BRUCE K. BROWN, general manager of research and development for the Standard Oil Co. of Indiana, has been elected a member of the board of directors of the company. He joined Standard of Indiana in 1929, having previously practiced patent law and served Commercial Solvents Corp. and Burgess Laboratories in technical and patent capacities. He was first general patent attorney for Standard and later manager of the development and patent department before being promoted to his present position in 1938. He now supervises the research activities at the six refinery laboratories.

✦ DONALD R. MYERS, who recently received his doctorate in organic chemistry from Ohio State University, has joined the research staff of Battelle Memorial Institute, Columbus, Ohio, according to the announcement by Clyde E. Williams, Institute director. Dr. Myers will carry on research in cellulose chemistry.

✦ BOB KOCH, formerly assistant sales manager of the Morse Chain Co., will manage the new branch office recently established at Houston, Tex.

✦ JAMES D. FLEMING has been appointed vice president and sales manager of Grinnell Co., Inc., Providence, R. I. He has been associated with the company since 1919 and while he will continue to manage the subsidiary company on the Pacific Coast, he will be located at the company's headquarters in Rhode Island.

✦ BAYNARD R. WHALEY has joined the research staff of Sonoco Products Co. of Hartsville, S. C. He was formerly with Firestone Rubber and Latex Products Co. of Fall River, Mass.

✦ WILLIAM B. DOBSON has been appointed works manager of the Oil City Tank & Boiler Co. of Oil City, Pa. For many years Mr. Dobson was superintendent of the heating boiler division of Struthers-Wells Titusville Corp.

✦ FREEMAN P. STROUP, senior active member of the faculty at the Philadelphia College of Pharmacy and Science, will be honored during the annual commencement week program. The homecoming day dinner of the Alumni Association on June 4 will be dedicated to Professor Stroup. In addition to being professor of organic chemistry, he is recording secretary of the Alumni Association.

✦ EDWIN C. SCHREIHART, works chemist for the past five years, has been appointed plant manager of the Heresite & Chemical Co., Manitowoc, Wis. Henry Wernecke has been appointed sales manager of the company.

✦ NORMAN L. DEUBLE is now associated with the Copperweld Steel Co. at Warren, Ohio as assistant to vice president. He was previously with the Republic Steel Corp. and has been associated with the Central Alloy Co. and the United Alloy Steel Co.

✦ P. W. FOSTER, JR. has been appointed manager of the steam division of Foster Wheeler Corp. Martin Frisch, formerly chief engineer of that division, has been appointed to the corresponding position of the corporation.

✦ E. T. ASPLUNDH has been elected vice president of the Pittsburgh Plate Glass Co. in charge of the company's chemical and cement operations, succeeding Hugh A. Galt who retired recently. Previously Mr. Asplundh held the position of assistant to Mr. Galt. He first joined the Pittsburgh Plate Glass Co. organization in 1919.

✦ CALEB DAVIES, JR. has been elected vice president in charge of tar products of the Pittsburgh Coal Carbonization Co., according to the announcement of Mr. C. E. Lesher, president.

✦ C. M. HOFF has become manager of the Electro-plating Division of the E. I. duPont de Nemours & Co., vice J. C. Pickard, transferred to the R. & H. Chemicals Dept. and F. F. Oplinger has become assistant manager of the Electro-plating Division vice Mr. Hoff.

CALENDAR

MAY 27-31, **American Petroleum Institute, mid-year meeting, Fort Worth, Tex.**

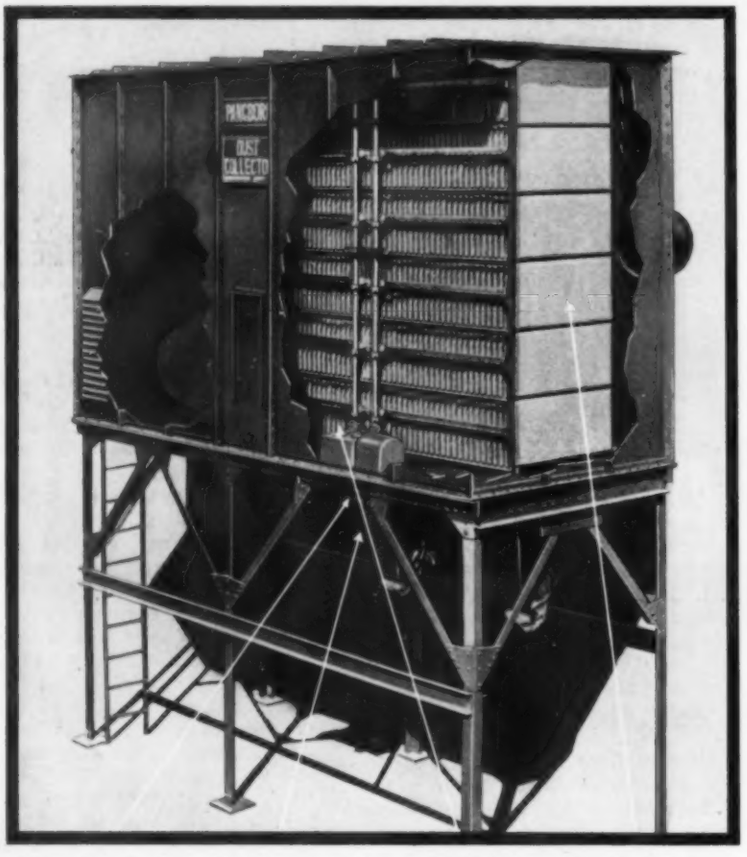
AUG. 20-23, **Technical Association of the Pulp & Paper Industry, fall meeting, Olympic Hotel, Seattle, Wash.**

SEPT. 9-13, **American Chemical Society, fall meeting, Detroit, Mich.**

OCT. 2-5, **Electrochemical Society, fall meeting, Ottawa, Canada.**

DEC., **American Institute of Chemical Engineers, New Orleans, La.**

PANGBORN



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✦ GUSTAV EGLOFF, director of research of University Oil Products Co., Chicago, is the 1940 recipient of the medal which is awarded annually by the American Institute of Chemists for outstanding service to the science of chemistry and to the American chemical profession. The medal was presented at the Institute's annual meeting held at Atlantic City, May 18.

✦ FRANK L. LAQUE who has been assistant director of the technical service on mill products for The International Nickel Co., is now engaged in development activities on all applications of both ferrous and non-ferrous nickel containing alloys. He will continue to make his headquarters in New York.

Harold F. Pitcairn

✦ HAROLD F. PITCAIRN has been elected president of the Southern Alkali Corp., subsidiary of the Pittsburgh Plate Glass Co., succeeding Hugh A. Galt, who retired recently. Mr. Pitcairn is a director of the Pittsburgh Plate Glass, president of the Autogiro Co. of America, and proprietor of the Pitcairn Autogiro Co. He has been associated with the Pittsburgh Plate Glass Co. for many years, first serving in its efficiency department in 1919.

✦ C. D. BLACKWELDER, a partner in the firm of J. E. Sirrine & Co., Greenville, S. C., was recently initiated into the North Carolina State College Chapter of Tau Beta Pi, national honorary engineering fraternity.

✦ A. W. LIMONT, JR. has become affiliated with the Titusville Processing Equipment Div. of Struthers-Wells. For many years he was with E. I. duPont de Nemours & Co., Inc., specializing in chemical plant equipment and design.

✦ MORGAN B. SMITH has been added to the technical organization of the Detroit Testing Laboratory. Since 1912 he has been employed in research and advisory work by the Detroit United

Railways, The Detroit Edison Co. and General Motors Corp. Previously he was employed as research chemical engineer by the Solvay Process Co. and the Semet Solvay Co., Syracuse, N. Y. Mr. Smith will devote his time to personal contacts with old and prospective clients, endeavoring to increase the scope of the good will long enjoyed by the Testing Laboratory.

✦ JAMES C. MORGAN has been promoted from his former post of general sales manager of the Philadelphia Division to the position of general manager of the entire Philadelphia plant of Yale & Towne Mfg. Co.

✦ HENRY BOOTH, E. L. MILLS and PHILIP KEARNY have been elected president, vice president and treasurer respectively of International Acetylene Association for 1940. H. F. Reinhard was re-elected secretary. Mr. Booth is now vice president of Shawinigan Products Corp. of New York. Mr. Mills is vice president of Bastian-Blessing Co. of Chicago. Mr. Kearny is founder and president of K-G Welding and Cutting Co. of New York. Mr. Reinhard is associated with the Union Carbide Co., New York.

✦ THOMAS E. COCKER has been appointed manager of the Detroit office of Chain Belt Co. of Milwaukee, to succeed G. A. Gunther. Mr. Klemme will succeed Mr. Cocker as manager of the Buffalo office. He has been with the company since 1935, serving in both engineering and sales departments. Robert Potter, a member of the home office sales organization has been transferred to the Pittsburgh office where he will assist Mr. Gayle Sherratt, district manager.

✦ RICHARD LUTHER has been appointed by the Vita-Var Corp. paint manufacturers of Newark, N. J. to take charge of their industrial sales and export divisions. Mr. Luther was associated for more than 21 years with Certain-teed Products Corp. in charge of their export sales, but resigned his position to become associated with Vita-Var.

✦ FRANK GRISWOLD HALL, president of Stein, Hall & Co., was tendered a banquet by the officers and directors of the company in celebration of the 50th anniversary of his association with the organization. The banquet was held in the Waldorf-Astoria Hotel on April 6, just a half century from the day when Mr. Hall replied to a newspaper "Help Wanted" ad which won for him a $9-a-week job with the late Leo Stein.

✦ GEORGE FREESE has been appointed technical consultant for the Pioneer Asphalt Co. His headquarters will be at the new Chicago plant of the company. Mr. Freese, who was previously at the company's Lawrenceville plant in the capacity of chief chemist, will now be able to devote his entire attention to problems pertaining to the development of new types of asphalts and their improved applications.

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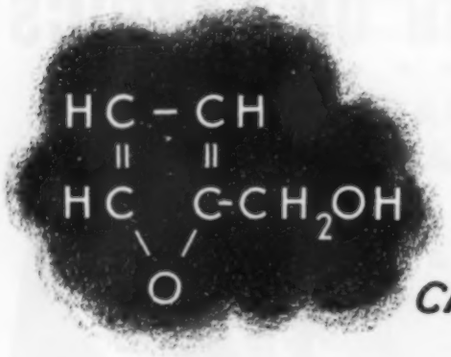

A Furfural derivative with unique characteristics

SPECIFICATIONS

Distillation range: 90% between	165-177° C.
Specific gravity 20/20	1.130-1.136
Color	Straw yellow to amber

PROPERTIES

Melting point	—20° C.
Flash point	75° C.
Refractive index 25/D.	1.4850
Vapor pressure (50° C.)	4mm.
Surface tension	38.2 dynes/cm.

SOLUBILITY AND REACTIVITY

Furfuryl Alcohol is a dispersant for dyes, many resins, both synthetic and natural, and cellulosic derivatives. It is miscible with most organic solvents except paraffinic petroleum hydrocarbons. In general its reactions are typically those of a primary alcohol with the exception that it is resinified by contact with mineral acids or strong alkalis.

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Many uses of Furfuryl Alcohol are based upon its solvent, penetrating, and wetting properties. Thus it finds application as a textile dye solvent and also acts as a fixative as well as renders the finished cloth more color stable. It is reported to assist materially in the mercerization of cotton. Other uses include its application as a solvent-plasticizer in the manufacture of abrasive wheels, and when converted into Furfuryl Xanthate it has proved useful as a flotation agent. Chemical-resistant coatings are produced when Furfuryl Alcohol is polymerized in situ by the action of dilute mineral acids or acid salts.

SHIPPING INFORMATION

Containers	9, 45, 90 lb. tins; 500 lb. drums; drum carloads	
Weight per gallon	9 lbs. (for billing purposes)	
F. O. B. Point	Drums	Waverly, New York
	Less than drums	Cedar Rapids, Iowa

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FURFURAL - FURFURYL ALCOHOL - HYDROFURAMIDE
... TETRAHYDROFURFURYL ALCOHOL ...

✦ FREDERICK S. BACON has been appointed assistant professor of chemical engineering at Northwestern University.

✦ MERLE GRIFFIN, at present with the market and sales development section of Shell Development Co., in Emeryville, Calif., will become head of a similar department of Westvaco Chlorine Products, New York, N. Y.

✦ WALTER L. BADGER, manager of the Consulting Engineering Division of the Dow Chemical Co. was named winner of the William H. Walker Award of the American Institute of Chemical Engineers. The Award is made for outstanding contribution to chemical engineering literature.

Walter L. Badger

✦ MYRON T. HERREID was elected vice president of Koppers Co. in charge of the Minnesota division, which operates coke ovens, processes tar and sells gas and coke. He succeeds E. L. Smith who has temporarily withdrawn from active management of the plant.

✦ CHARLES S. BRADEEN has been appointed to the position of executive vice president of the Canadian Fairbanks-Morse Co., Montreal.

✦ JOSEPH V. SANTRY has been elected president of Combustion Engineering Co.

✦ GEORGE W. DOLAN and C. S. GLENN have been elected vice presidents of Mathieson Alkali Works, Inc.

OBITUARY

✦ W. J. STODDARD died unexpectedly Apr. 23 when he was stricken with a heart attack in his office. He was 62 years of age. He had developed the dry cleaning solvent that bears his name and was president of the Stoddard Dry Cleaning & Dyeing Co., Atlanta, Ga.

✦ A. M. GREAVES-WALKER, assistant to the chief technical engineer of Libbey-Owens-Ford Glass Co., Toledo, and son of Dr. Arthur Greaves-Walker, professor of ceramic engineering at North Carolina University, was killed in-

stantly in a train wreck at Little Falls, N. Y., April 19. He was 32 years of age.

✦ ERWIN SUHM, secretary and director of research for the Suhm Co., died April 22. He was 54 years old. He had been associated for about 32 years with the firm formerly the Cream City Chemical Works which had been founded by his father, John J. Suhm, president.

Carl Bosch

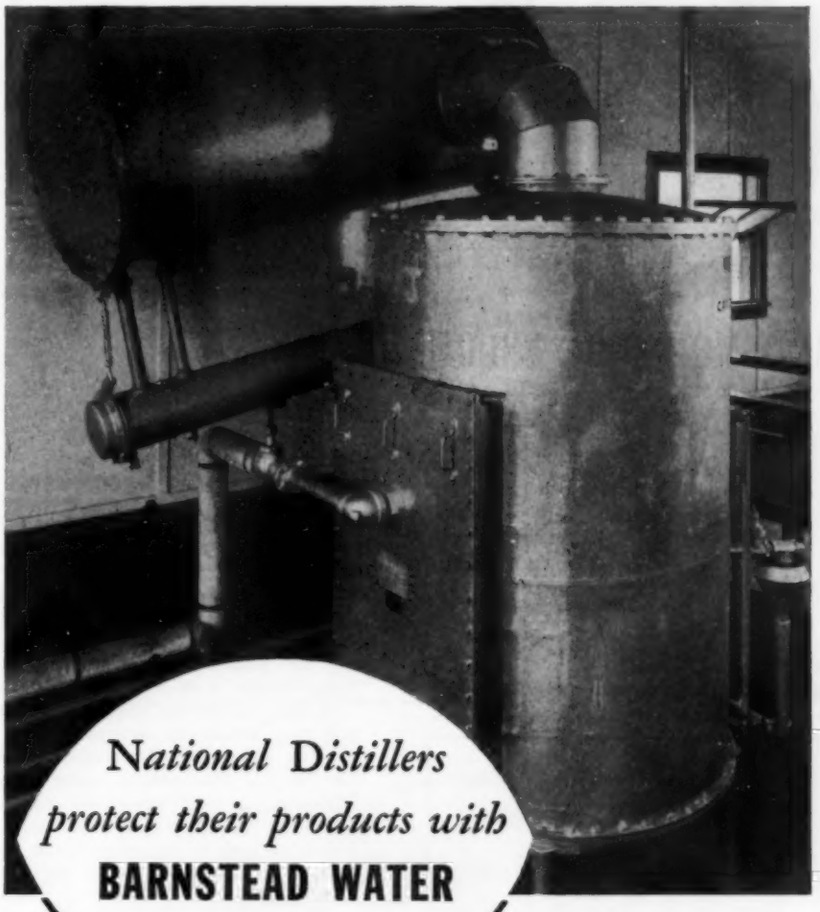
✦ CARL BOSCH, chairman of the I. G. Farbenindustrie A.G. and winner of the 1931 Nobel prize for chemistry, died at his home in Heidelberg Apr. 26. He was 65 years old. In 1937 Dr. Bosch was honored, being made president of the Kaiser Wilhelm Society for the Advancement of Science, Germany's foremost scientific institution.

From a snapshot taken April 1940

Edwin F. Northrup

✦ EDWIN FITCH NORTHRUP died April 29 at his home in Princeton, N. J. after an illness of several weeks. He was 74 years old. Dr. Northrup received the bronze medal of the Exposition Universalle in Paris in 1900 for his contributions to the Rowland telephone system. He also was awarded the Edward Longstreth medal in 1912, the Elliott Cresson medal in 1916, and the Edward Goodrich Acheson gold medal in 1931.

Here's How!



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Chemical & Metallurgical Engineering

READERS' VIEWS AND COMMENTS

Readers are invited to express their views on articles appearing in Chem. & Met. *or on other subjects of interest to chemical engineers. As far as our space permits such views and comments will be published in these columns. Address your letter to the Editor of* Chem. & Met., *330 West 42 St., New York, N. Y.*

To the Editor of Chem. & Met.:

Sir:—Several years ago while going through some of my father's papers I came upon the following list of "Rules for the Executive" which he wrote some time before his death in 1924. I feel that they are so concise and pertinent that your readers might be interested in seeing them. They are presented just as I found them. Although he titled them "A Pedantic Discussion," I believe they are anything but pedantic.

RULES FOR AN EXECUTIVE BY ONE OF THEM TO ANOTHER
A Pedantic Discussion
John G. D. Mack

1. Never do anything which it is possible for a subordinate to do unless the element of personal danger enters. Your chief business is supervision, readiness to serve, to make policies and to meet ever rising emergencies.
2. In everything which does not seriously interfere with you or your trust, give others their own way as far as possible. Wrangling over petty details of no consequence as to how they are solved blocks progress and may wreck the enterprise.
3. Give all credit to subordinates for, if you like credit, more than sufficient for your needs will reflect on you. It is a far more commendable task to select or train an efficient employee than to do the work yourself.
4. Do not fear a subordinate who is a better man than you are but endeavor to equip your department with such men and take a just pride in the fact.
5. All essays on loyalty deal with loyalty of subordinate to superior. Be loyal to your subordinates and they will be loyal to you.
6. Encourage criticisms or suggestions for betterment from all sources and receive them kindly although you may be able to apply but few of them.
7. Be considerate of others' opinions even though you may know them to be wrong.
8. Give undivided attention to the matter in hand and never show evidence of being in a "hurry," for that trait is like a slipping clutch. A tiresome interview can be happily terminated at any time.
9. Express appreciation for service well performed, even though the employees be paid for that service.
10. If a verbal order which you give goes wrong, absorb the blame and forget it.
11. Be brief, but tell all the leading facts or none.
12. Never use "to speak frankly" or similar phrases for the other person will immediately and possibly with justice jump to the conclusion that your statements lacking this qualification are full of dissimilation.
13. Always be polite in word and action. Politeness is an impenetrable armor.
14. Never scold nor show anger. If you scold you are a joke as soon as your back is turned and if you show anger it is a break in your armor which places you at the mercy of a skilled antagonist.
15. Never make a show of authority until all else has failed, but in this almost impossible emergency use your authority to the limit.
16. Have endless patience.

My father, John G. D. Mack, was a Professor of Machine Design at the University of Wisconsin for many years and was Chief Engineer of the State of Wisconsin for the ten years preceding his death. He was very widely known as a teacher and an executive and these rules apparently represent his observations and experiences gathered in many years of successful professional engineering work.

DAVID J. MACK
Professor of Chemical Engineering
University of Tennessee
Knoxville, Tenn.

TWILIGHT ZONE IN EDUCATION

To the Editor of Chem. & Met.:

Sir:—I am fifty-four. There are a few things I'd like to do while I am still able. You might call them "generalizations" based on my twenty-five years teaching experience. One of them is to participate in the development of a new type of chemical technician course which would both train and educate—in the area between the vocational school and the "technical" high school.

Kipling has a story which ends with his British Tommy telling his mates that he found his Boer captor trying to "erect an aristocracy upon the sjambok." I am fearful of a similar attempt by men in certain chemical circles to turn their backs upon the example of men like Faraday, Hart and Carver and erect a chemical aristocracy upon college degrees, barring those who might rise from the ranks. There has been a similar move in the legal profession and medicine is a closed "trade." Such efforts may make our country as futile and its institutions as extinct as those of the Mayas who also concentrated education and science in the hands of a single class or caste.

I have found 17-year-old boys apt enough to take Fiegl's "Spot Tests" (Janet Matthews' translation) without much help, and make 80 per cent or better on simple unknowns without group separations. The same group made several grams of the costly and involved reagent para benzylidene rhodanine for copper and silver tests. They set up distillation equipment which secured a 28-in. vacuum. These were boys out of the working class of Wilmington—a "dead-pan" blonde Polish boy with bad teeth as a result of malnutrition, a round-faced Irish boy and a slim White Russian from "across the tracks." Are they to be denied the chance to progress and told that they can never go higher than $1,800 per year?

Northwestern University once tried to get a collection of high I.Q. children for an experimental school. Only two of the 13 or 15 children came from families which were able to send them. The project was abandoned. Genius too often occurred in families in which the income was less than $2,500 per year.

What is the answer in these days of rising educational cost in law, engineering, and medicine when the public grows more and more sure of its dissatisfaction with current secondary education in spite of all its "progressive" front? Where are there any tests of scientific aptitude to sort out embryo Edisons, Heavisides, Lammes, Steinmetzes and Ketterings? Who will give the price of a horse for another Carver, white or black? Are we to maintain an educational *laissez faire* policy with its inevitable and distressing waste?

Suppose for a moment that we could work along the line of the recent Spens Report to the British Science teachers (Nature, Mar. 4, 1939, Vol. 143, p. 349)—take a selected group of boys into the facilities of (1) a university high school plus (2) the equipment of a university chemical engineering department in the final years. I am sure that we would get a high grade technician who could not only go into lab and plant but also into the university or engineering school when his funds permitted. First, we would need to determine that the boy had "the seeing eye and the inquiring mind." Can you doubt the value of the results?

There is a big job in this twilight zone between chemistry and education. My real interest is there, and I would like to have a hand in some organized effort in this direction.

R. E. Bowman.

Headquarters C.C.C.Co. 3220,
Georgetown, Del.

CORRECTION

In the pictured flow sheet "Modern Sugar Refining," (February 1940 issue of *Chem. & Met.*, p. 119), it was stated that no char or vegetable carbon is used in the new Sucrest sugar refinery. This statement was incorrect. Darco is used at the present time in the Sucrest process, as well as Sucro-blanc.

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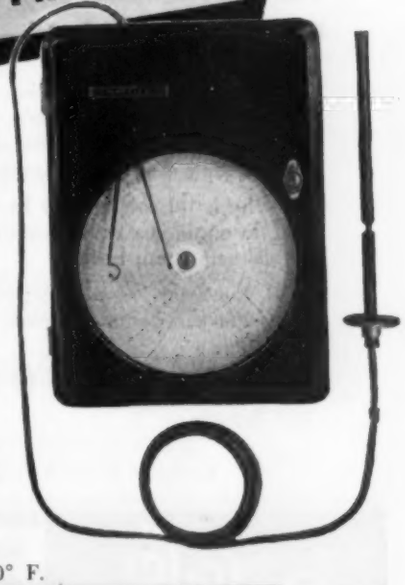

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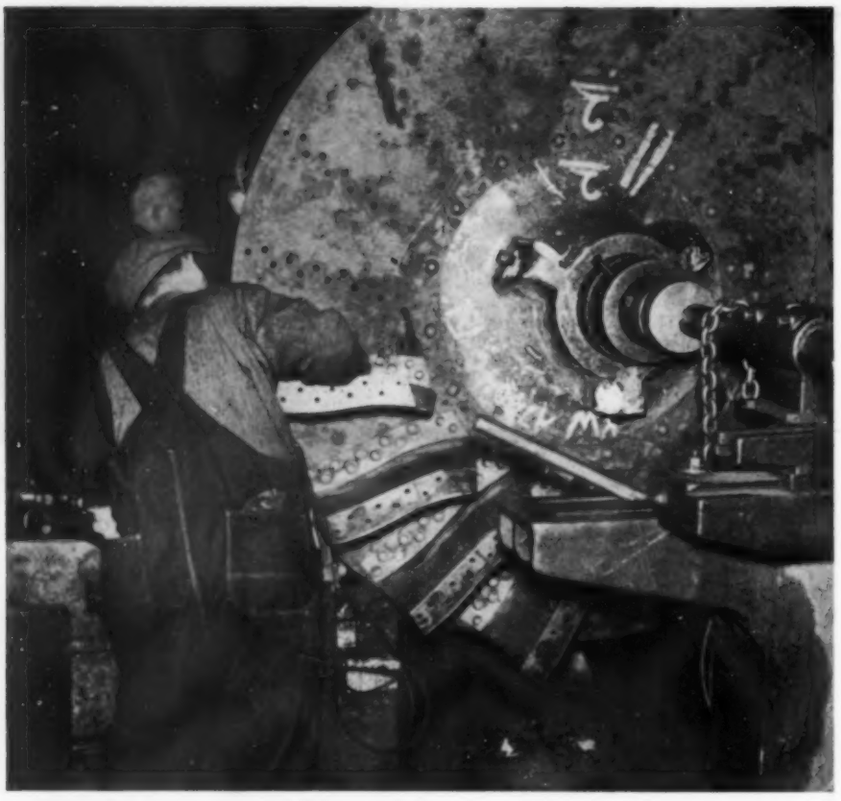

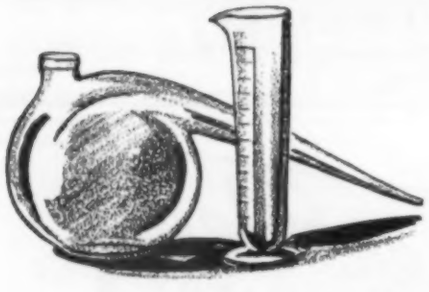

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(*Continued from page* 343)

ous possible combinations of three sizes of copper tubing and four sizes of standard iron pipe. A graphical differentiation of the coefficients against velocity yields liquid film coefficients which have been analyzed. A more accurate expression of results is obtained with the Nusselt equivalent diameter and the substitution of 0.04 D_2/D_1 (the ratio of the boundary diameters of the annulus instead of the value, 0.0225, heretofore recommended in the Dittus-Boelter equation.—Alan S. Foust, University of Michigan and Gene A. Christian, E. I. du Pont de Nemours & Co.

Glass Exchangers—This paper presented results of heat-transfer measurements in double-pipe exchangers, the inner pipes being of Pyrex glass, 1 in. and 2 in. in diameter. The results indicate that non-boiling coefficients may be computed from the Dittus-Boelter equation, using an increased numerical coefficient for calculation of the annulus film. Measurements for condensing steam indicate that the resistance of the steam film is very small compared to the water film, even though the amount of condensate accumulating is quite large.

Coefficients for dehumidification of wet air are presented as a nomograph covering air velocities from 13 to 135 ft. per sec. and moisture contents from 10 to 60 per cent, both at entering conditions. Cooling water was used at temperatures from 50 to 95 deg F. entering and rates from 0.3 to 3.3 ft. per sec. The mass transfer rates corresponding to these coefficients correlate consistently 25 per cent below the results of Colburn and Hougen for a vertical tube, which was much shorter than the four pass exchangers used in this investigation. In a surprising number of conditions, the condensing film coefficients are high enough that the water film offers the dominant resistance. Evidence indicating that the thermal conductivity of Pyrex is higher than published values was also discussed.—Alan S. Foust, University of Michigan, and T. J. Thompson, Corning Glass Works.

Evaporation and Drying—Overall coefficients of heat transfer were determined when drying a crystalline material from a 40 per cent water solution in a 350-gal. jacketed kettle equipped with positive scraping agitator. Design of equipment and operating data were presented.—H. G. Laughlin, the duPont Co.

Turbulent Flow—An analysis of the

published data on the velocity distribution of fluids in turbulent flow has shown that these data are consistent with theoretical formulas already advanced. A discussion of the results underlying the apparent discrepancies is advanced and experimental data are used to substantiate this.—H. T. Bates, Iowa State College.

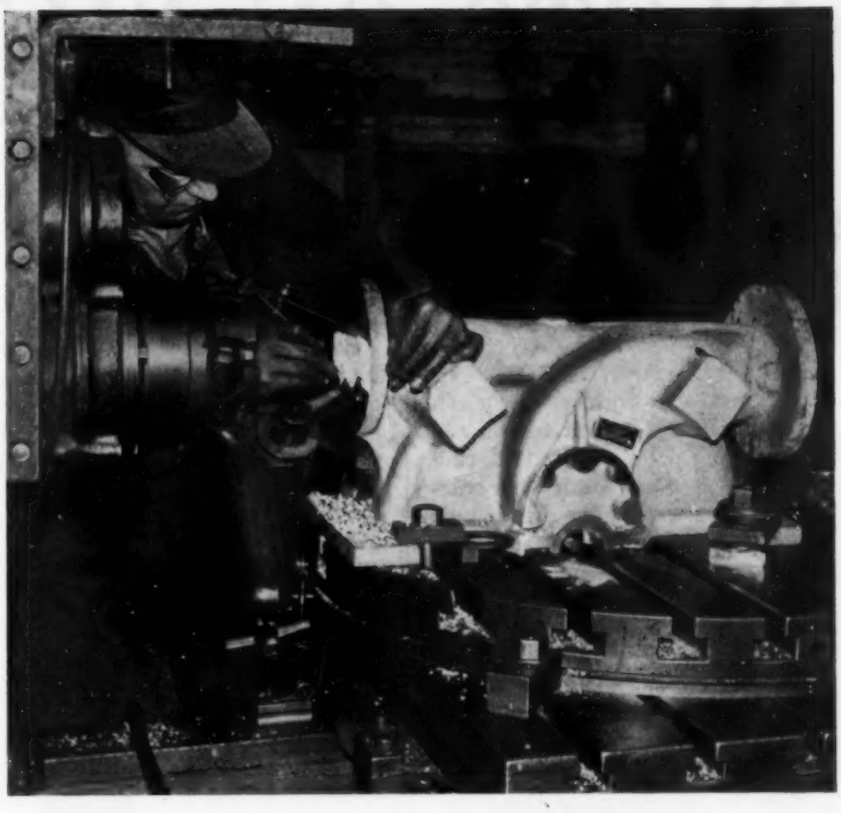
Heat Transfer—Coefficients of heat transfer from vapor to a horizontal tube were determined for the condensation of mixed vapors of water and non-miscible organic liquids. This work is an extension of the research previously published by Baker and Mueller. In the present work a much wider range of vapor compositions was studied.—E. M. Baker and Utah Tsao, University of Michigan.

Sedimentation—This paper comprises an experimental study of two types of suspensions over a wide range of concentrations and with different settling heights, with a view toward correlating these variables into general relations for the settling periods.—Lincoln T. Work, Columbia University and Arthur S. Kohler, Newark College of Engineering.

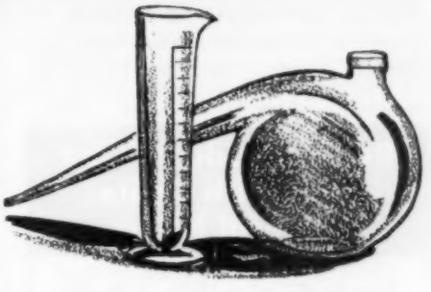
PAPERS BY TITLE

Four papers originally prepared for the Second Chemical Engineering Congress, scheduled to be held in Berlin, Germany, in June 1940, were presented by title. The first of these by Frederick G. Straub of the University of Illinois, discussed new trends in boiler feed and water treatment. It will be published in full in an early issue of *Chem. & Met.* Dr. Francis C. Frary, Director of the Aluminum Research Laboratories, of New Kensington, Pa., titled his paper "Aluminum Chemical Equipment." Percy C. Kingsbury, Chief Engineer of General Ceramics Co., had prepared a paper entitled "The Development of Ceramic-ware for the Chemical Industry." Dr. Charles M. A. Stine, Vice-President, E. I. du Pont de Nemours & Co., Inc., had titled his address "Chemical Engineering and Industry."

Stine defined chemical engineering as a philosophy affecting all relationships which involve energy and material. Since chemical engineering is closely identified with new products and new processes, as well as increased production efficiency, Dr. Stine thought it desirable to dispel the concept so frequently voiced that science lessens employment. The fact is that over long periods of time, industrial employment has increased at a rate greater than the population. Chemical engineering, said Dr. Stine, is the agency by which many important industries have been created.



PUMP BUILDERS



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FACTS ON FILTERING

Representative case histories on widely varied clarification problems condensed from field reports of Johns-Manville Filtration Engineers

Varnish Filtered Ten Times Faster

(Reported by J-M Engineer K. L. Rohrback)

CINCINNATI DISTRICT—In this varnish plant, trouble was reported filtering Kauri gum varnish. Filter aids had been tried, but without improvement. If not centrifuged before filtration, only 200 gallons could be put through the press in a full day's run. A check-up indicated that Celite No. 501 should produce a clear filtrate at high flow rates with existing filters. Accordingly, a test run was started.

Results far exceeded the company's expectations. In 4 hours, 20 minutes, 1050 gallons of varnish were filtered . . . more than ten times the amount previously secured. Centrifuging before clarification is eliminated. And by speeding up the pump, even faster filtration will be possible with this high-flow-rate filter aid.

$9100 Per Year from Scrap Sugar

(Reported by J-M Engineer P. R. Deschere)

NEW YORK DISTRICT—Because of our success in similar plants, I called on this candy manufacturer several months ago to investigate the possibilities of savings through scrap sugar recovery.

I found that their scrap accumulated from batch ends, imperfect pieces, etc., at a weekly average of 6000 lbs. Of this total, 1800 lbs. is clean scrap which they had been returning to the sugar refinery in exchange for new sugar at a differential of 1¢ per lb. The balance of 4200 lbs. is colored and had formerly been discarded.

Based on our analysis, which showed that appreciable savings could be made by filtration and recovery of waste scrap, they bought a filter and some Hyflo Super-Cel filter aid.

The results have been very satisfactory. At an overall cost of less than ½¢ per lb., they are now recovering all their sugar, both clean and colored, at a net saving of about $175 per week.

Oil Refinery Cuts Filtering Costs

(Reported by J-M Engineer H. N. Haberstroh)

CHICAGO DISTRICT—This large oil refinery, filtering residue at 600° F. from cracking units working on lime-neutralized crude, was having trouble with high filter-aid costs, short filter-screen life and erratic B. S. in filtrates.

Our engineers corrected the precoating technique and altered the method of steaming the filter cake to remove retained oil and to cool the filter to a safe temperature for opening and cleaning.

These changes resulted in greater filter capacity, longer screen life and sizable reductions in the amount of filter aid needed. The cost of the alterations that made these savings was paid for by steam saved alone in the first six months.

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In hundreds of cases like those reported here, J-M Engineers have stepped up flow rates, improved clarity, cut costs. They can show you exactly the type and grade of filter aid you need for best results in your filtering . . . give it to you from the complete line of J-M Celite Filter Aids.

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New Titles, Editions and Authors

Chem & Met BOOKSHELF

THE TOOLS OF THE CHEMIST. Their Ancestry and American Evolution. By *Ernest Child*. Published by Reinhold Publishing Corp., New York, N. Y. 220 pages. Price $3.50.

Reviewed by *S. D. Kirkpatrick*

A CHANCE REMARK by chemistry's leading historian, Dr. Charles A. Browne, led to the writing of this little book. In a brief footnote to an article published in 1932, Dr. Browne mentioned that the story of the early development of chemical apparatus "deserves to be written up as a part of the history of chemical education in America." That challenge was accepted by Ernest Child, president of H. Reeve Angel & Co., who for more than 30 years has been associated with manufacturers and dealers in laboratory equipment both in America and in Europe.

What resulted was an intensely interesting history of the men whose names will always be associated with the chemical laboratory. Liebig for his original condenser, Hempel for his gas analysis apparatus, Kjeldahl for nitrogen determination, Kipp for gas generator, Buchner and his funnel, Geissler and the Sprengel-Geissler pump that was used by Edison in evacuating the first electric light bulb — behind each of these is a personality and a story that the author has told with rare brilliance.

More than half the book deals with the ancestry and development of American chemical laboratory apparatus and particularly of the firms that as distributors of such supplies contributed their part to the development.

Those of us who are interested in the history of chemistry and its related industries and professions are indebted to Dr. Browne for having catalyzed this chemical reaction. Chemical engineers would welcome a similar stimulation that might result in a comparable history of the larger tools such as the equipment and machinery of the unit operations and processes.

ABOUT JOBS

ENGINEERING OPPORTUNITIES. Edited *by R. W. Clyne*. Published by D. Appleton-Century Co., New York, N. Y. 397 pages. Price $3.

IN AN interesting foreword, Dr. Karl T. Compton writes: "We owe the authors of this book a real debt of gratitude for bringing together a bird's-eye view of the fields of engineering for all of those who are interested in making its closer acquaintances." Thus is made easier the work of all who are called upon to help the young man in choosing the right career.

Twenty-six well-informed engineers contribute as many chapters on the opportunities that exist in their fields —ranging from the aluminum industry, so interestingly portrayed by S. K. Colby, vice-president of the Aluminum Co. of America, all the way through to mechanical vibrations as a specialized industrial application of physics, described by Leonard C. Peskin, research engineer of the American Steel & Wire Co.

Chemical engineers will be directly interested in chapters on food technology, glass, petroleum industry, plastics, refrigeration and air conditioning, the rubber industry and indirectly, in practically every other chapter because this is a book that presents all engineering opportunities where it finds them.

HANDBOOK OF CHEMICAL MICROSCOPY, Vol. II, Second Edition. By *E. M. Chamot* and *C. W. Mason*. Published by John Wiley and Sons, New York, N. Y. 438 pages. Price $5.

SINCE the second edition of Vol. I of this microscopists' Bible appeared, the revision of Vol. II has probably been impatiently awaited by hundreds to whom microscopy is vocation, avocation or both. Nor is anyone going to be disapopinted. Side-by-side comparison of the two editions reveals numerous additions by which the newer improves upon its predecessor. For example, the book now contains more recent discoveries concerning such matters as the triple acetates of lithium, sodium fluogermanate, reactions with diphenylcarbazide, separation of columbium and tantalum, separation of halates and many other small but important improvements. There are 48 new photomicrographs, most of them being of crystals formed with organic reagents such as tetraethylammonium chloride, hexanitrodiphenylamine and nitrobarbituric acid. The reproduction of these illustrations is much clearer than in the old edition. The new book in order to accommodate all the new material without unduly increasing its size, is printed in entirely legible but slightly smaller type and there are a few more lines per page.

RUBBER LATEX. By *H. Stevens* and *W. Stevens*. Published by Chemical Publishing Co., New York, N. Y. 224 pages. Price $2.

Reviewed by *D. F. Othmer*

THIS book is evidently a reprint of the Fourth Edition of what the authors call "this small pamphlet . . . on Latex." They make no claim to treating the subject completely or exhaustively, as they state that such treatment would be impossible within the limits set, some 200 pages. There seems no reason to call this, as is done on the title page, "the first American edition," since it has no features peculiar to this country at all. It does have over one hundred pages of abstracts of British patents referring to Latex but there is no similar abstracting of United States patents. The book does seem to fulfill the need of a brief introduction to the subject matter of Latex and this is particularly important in this country at the moment when it is considered that over sixty million pounds of Latex were imported in 1939 as compared to less than half as much for the previous year, the increase being due largely to the development of cushioning material. There is a discussion of the source and production of Latex, its properties, concentration, manipulation and compounding, stabilization, and vulcanization. Other chapter describe the manufacturing from Latex by dipping and electrodeposition, the application and marketing of Latex products, and the English patent abstracts with a good index to both patents, patentees, and the text as a whole.

BOILER WATER

BOILER FEED WATER TREATMENTS. By *F. J. Matthews*. Published by Chemical Publishing Co., New York, N. Y. 319 pages. Price $5.

Reviewed by *H. T. Hotchkiss, Jr.*

ORIGINATING in Great Britain, this book pays tribute to the strong attack America has made on water conditioning problems by referring, in the majority of cases, to the literature of the United States. The author has attempted the difficult task of translating advances in a complex technology into terms which the "small average" steam plant operator may understand. As chapters progress, simplicity is abandoned for discussions of colloidal theory, ionic theory, electrochemical reaction, pH, thermodynamics and so on.

The book has undergone real revision to include many recent topics such as carbonaceous zeolites, threshold treatment, siliceous impurities and "starvation" treatments combining the benefits of organic colloidal matter with those of inorganic chemicals. Slime in condenser circulating systems is attributed to algae rather than to slime bacilli and control by chloramination receives no mention. Readers are cautioned that where supplementary calcu-

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HOW TO USE PHYSICAL CHEMICAL METHODS

TO CONTROL AND PREDICT THE DIRECTION AND YIELD OF CHEMICAL REACTIONS

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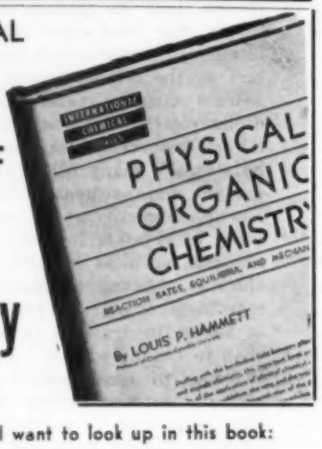
Physical Organic Chemistry

By LOUIS P. HAMMETT, Professor of Chemistry, Columbia University, 404 pages, illus., $4.00



THIS book presents the results of the application of physical chemical methods to the problems of the equilibrium, the rate and the mechanism of the reactions of organic chemistry, that is, to the prediction of the direction and the yield of the organic chemist's procedures. The material, most of it the result of very recent theoretical and experimental discoveries, and available only in the periodical literature, is of great importance to both physical and organic chemists.

You will want to look up in this book:

—the simplified presentation of valence theory in the light of results of quantum mechanics;

—the proton transfer theory of acids and bases and the Bronsted theory of catalysis;

—the effect of structure on reactivity;

—a survey of the mechanisms of organic chemical reactions.

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lations have been given, the British gallon has been utilized. Only the weight relationship to the U. S. gallon is given in the conversion tables of the appendix. Critical comments on the comparative merits of methods outlined has not been given. The space given to analysis and routine testing might well have been curtailed to a simple list of source materials and the saving utilized in amplification of part I on natural water supplies.

MICRO-DIFFUSION ANALYSIS AND VOLUMETIC ERROR. By *Edward J. Conway*. Published by D. Van Nostrand Co., New York, N. Y. 306 pages. Price $6.

Reviewed by *G. F. Kinney*

THE DOUBLE TITLE of this treatise perhaps indicates something of its nature; the author in one book is contributing to the field of microchemistry, theoretical volumetric analysis and biochemical practice.

Micro-diffusion methods can to a certain extent replace distillation methods, particularly in the determination of ammonia, carbon dioxide or halogen. The transfer of gas from treated sample to absorbing liquid is complete in an hour or so when small samples are used, and the rest of the procedure involves only a back titration or perhaps a colorimetric run. While this may take longer than is required for a distillation and back titration, the diffusion takes place completely unattended and there results a net saving of labor, time and apparatus in routine work. The complete theory of the micro-diffusion method is given and its advantages and limitations presented. The apparatus and manipulative details for representative analyses, particularly those of biochemical importance, are described in the apparently standardized microchemical manner.

Nearly half the book is devoted to an exhaustive theoretical study of the errors of volumetric procedure, both macro and micro. The author draws practical conclusions from the study and ample experimental support is furnished. Here are both theoretical and experimental answers (and they agree) to the question "Should the last drop in a pipette be blown out?"

This study of volumetric error permits a rational approach to the problems of design and use of pipettes and burettes; both equipment manufacturers and research workers can well benefit by the principles laid down. For example, by careful adherence to these principles the author indicates how to perform volumetric analyses at the one-tenth milliliter level with the same relative precision that is possible with a macro 25 milliliter titration. The effect of dilution on precision is then considered and the ultimate limit of acid-base titrations investigated.

The volume is well indexed, and contains a number of diagrams, pictures and a selected list of references. It is a worthwhile addition to the literature of analytical chemistry.

PRACTICAL MICROSCOPICAL METALLOGRAPHY, Third Edition. By *R. H. Greaves* and *H. Wrighton*. Published by D. Van Nostrand Co., New York, N. Y. 272 pages. Price $6.50.

METALLOGRAPHY is the study of the effect of structure and composition on mechanical and physical properties of metals and alloys. The term implies neither visual nor microscopical methods of examination but embraces all methods of study of structure and composition. This book is concerned, however, with this examination with the aid of a microscope and shows how mechanical properties such as hardness, ductility and the like may be correlated with microstructure. Divided roughly into thirds, the book covers microscopy, alloys of iron, and other metals and alloys. Discussions are complete and well illustrated with drawings and photomicrographs. The latter are clear, numerous and separately indexed which should make the book a handy reference.

FERTILIZERS

AMERICAN FERTILIZER PRACTICES (SECOND SURVEY). By *H. R. Smalley, Robert H. Engle,* and *Herbert Willett*. Published by The National Fertilizer Association, Washington, D. C. 128 pages. Price $1. (50 cents to members).

THIS IS A REPORT relating to the use of commercial plant food presenting information obtained by a survey among 32,000 farmers in 35 states. The various subjects discussed give an excellent idea regarding the present status of the fertilizer business and its important trends both in agriculture and in the use of chemical materials.

CALCIUM SUPERPHOSPHATE AND COMPOUND FERTILISERS. By *P. Parrish* and *A. Ogilvie*. Published by Hutchinson's Scientific & Technical Publications, London. 322 pages. Price, 35 shillings.

Reviewed by *A. M. Fairlie*

"ARTIFICIAL FERTILISERS," by the same authors and published in 1927, is the predecessor of the book under review, and has been regarded as the standard British work on the manufacture of superphosphate and mixed fertilizers for the past twelve years. This new edition, under a different title, is something more than a mere revision of the earlier work. There has been some consolidation and condensation of the old subject matter, and where necessary, the text has been re-written to bring the descriptions into accord with current practice. The chapters on "The Mining and Treatment of Phosphate Rock," on "Screening and Separating," on "Complete Grinding Installations" and on "The Trend of Future Developments" do not appear as separate chapters in the new edition; the treatment of "Mechanical Dens and Excavators" has ben altered to comprise two chapters, one on batch types and the other on continuous types of den equipment; new chapters have been introduced on "The Oberphos Process,"

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These 200-kva Pyranol transformers are installed in the motor room of the new cold-mill addition to the McLouth Steel Corporation plant, Detroit, Mich. They meant savings in installation costs, feeder costs, and copper losses, because *primary power was brought right to the load*

GENERAL ELECTRIC

302-6

"The Artificial Drying of Superphosphate" and "The Crystallisation and Fertiliser Products." Chapter XVII of the earlier work on the "Design of an Artificial Fertiliser Works" has been recast to include consideration of the structure of the British superphosphate industry. This new edition will no doubt retain the prestige of its predecessor.

Besides the new and re-written chapters mentioned, this new edition presents chapters giving a general survey of the fertilizer industry and of the world's supply of phosphatic minerals, and a discussion of the history and chemistry of superphosphate manufacture. Then follow chapters on rock crushing and grinding equipment and on wet mixing equipment. Other subjects considered, in three separate chapters, are the treatment of noxious gases, superphosphate storage and dry mixing systems. After these come chapters on "The Manufacture of Phosphoric Acid and Double Superphosphate"; "Manufacture of Bone Superphosphate"; "Manufacture of Basic Slag"; and "Mechanical Handling of Raw Materials and Products." The book closes with an Appendix containing some useful technical tables, conversion factors and statistics quoted from British census reports.

While this work naturally deals primarily with British practice, it is not parochial in its scope. Such American developments as the Oberphos process, the Broadfield and Sturtevant superphosphate dens, plant equipment manufactured by Dorr, Jeffrey, Tyler and others, and T.V.A. procedure are included. America is conceded to have "led the way" in the compounding of artificial manures.

The following items attracted the reviewer's attention as being of special use or interest: a series of tables showing the quantities of sulphuric acid of various strengths required per unit of various components of phosphate rock; specifications of the British alkali inspector on plant for the adequate treatment of noxious gases; the manufacture of sodium silicofluoride; an interesting diagram showing which fertilizer materials may be mixed and which should not be mixed; lists showing the appropriate composition of fertilizer mixtures for various crops; tables showing the annual production of sulphuric acid and the tonnages of raw materials used in the United Kingdom, years 1934–38; a detailed description of the Harris dust-suppressing mechanical furnace for roasting spent oxide, pyrite fines, etc.; and the design management of a superphosphate works, including a sulphuric acid plant. It is unfortunate that the misleading table of Kreps on sulphuric acid manufacturing costs, based as it is on faulty data and forced into balance, was reproduced.

The proof-reading has been exceptionally well done, and the type and printing are excellent. The index, on the other hand, is incomplete, and deficient in cross references. The book

is printed on paper of extraordinary weight and thickness, and as a result weighs 4 lbs., 6 oz. A 322-page book of such weight is not, strictly speaking, a hand book.

This new edition of an established work is recommended to all interested in the production of superphosphate or phosphatic fertilizers, or their raw materials or by-products.

WORK SHOP CHEMISTRY

MONEY-MAKING FORMULAS. Edited by *C. A. Crowley*. Published by Popular Mechanics Press, Chicago, Ill. 480 pages. Price $4.35.

HOW TO MAKE things is a fascinating study for a large percentage of the American public. None has reason to know that better than the editors of "*Popular Mechanics*" whose readers have long been asking how to make and do things involving chemistry.

To help to meet a need, they directed Mr. Crowley of the Technical Service Bureau, Inc., of Chicago, to compile as much thoroughly practical information as could be gotten into a 500-page book which would help the man who is more interested in the "how" than the "why" of chemical manufacturing. Not content, however, with publishing the usual type of formulary, of which there are already a number available, Mr. Crowley has added chapters on the development of new materials and products, on patents, trade-marks and copyrights, and supplemented it by a comprehensive index and a "Chemical Dictionary and Supply Directory." The dictionary and directory are much less comprehensive than many other volumes that are available, but they should prove useful and a welcome "dividend" on a good investment in the non-technical practices of work-shop chemistry.

PROCEDURE HANDBOOK OF ARC WELDING DESIGN AND PRACTICE. Sixth edition. Published by the Lincoln Electric Co., Cleveland, Ohio. 1117 pages. Price $1.50.

EARLIER editions of this encyclopedic handbook are undoubtedly familiar to all designers and manufacturers who use arc welding in any way. This new edition has about 20 per cent more material than the preceding edition, an indication of the advances made in the art during the past two years.

ADVANCED READINGS IN CHEMICAL AND TECHNICAL GERMAN. Selected and edited by *J. T. Fotos* and *R. N. Shreve*. Published by John Wiley and Sons, New York, N. Y. 347 pages. Price $2.50.

CONCLUDING the series of four chemical and technical graded readers, a series designed to facilitate study of German for chemical engineers and other students, this book contains selections from practical and widely used German reference books such as Beilstein, Gmelin and Ullmann. Graded according to difficulty and presented exactly as originally written, the selec-

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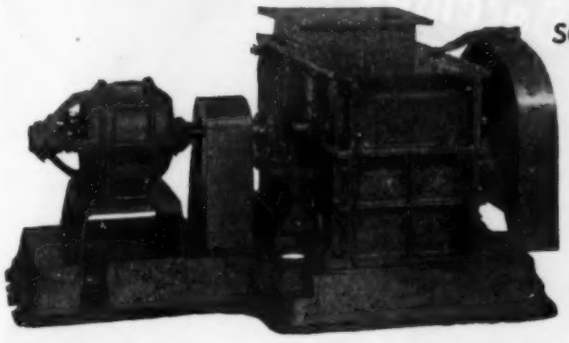

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tions will not only serve to teach the language but also present up-to-date chemical facts. In addition to the well annotated readings, the book contains an exposition on the main reading difficulties encountered in technical scientific German, a list of 2,250 words selected on a frequency basis and a 100-page vocabulary.

CHEMICAL CALCULATIONS, Fourth Edition. By *J. S. Long* and *H. V. Anderson*. Published by McGraw-Hill Book Co., New York, N. Y. 266 pages. Price $1.75.

RETAINING all the tested and accepted features of the previous editions, this revision has been made more usable by the addition of new material and some rearrangement of the old. From a chemical engineering viewpoint the book is much improved by the addition of material of less theoretical and greater engineering importance; for example, under specific gravity there is now included discussion of the Baume and A. P. I. scales. While the number of problems (845) is not much of an increase, there are many new ones, some of the less important from the previous edition having been omitted.

ORGANIC SYNTHESES, Vol. 20. Edited by *C. F. H. Allen*. Published by John Wiley and Sons, New York, N. Y. 113 pages. Price $1.75.

REGULARLY published, the books of this series give explicit directions for laboratory preparation of various organic compounds. Volume 20 contains directions for 39 such compounds, among them are acetylacetone, dimethylethynyl carbinol, diphenylketene and sodium amide. Procedure in all cases has been checked.

INDEX TO A.S.T.M. STANDARDS AND TENTATIVE STANDARDS. Published by American Society for Testing Materials, Philadelphia, Pa. 152 pages. Gratis.

ALL OF the A.S.T.M. standards as of Jan. 1, 1940 are here indexed and cross-indexed. This booklet will be of interest to those who may wish to know whether or not the Society has issued standard specification, test methods or definitions covering a particular engineering material or subject.

NATIONAL FIRE CODES FOR THE PREVENTION OF DUST EXPLOSIONS. Published by the National Fire Protection Association, Boston, Mass. 136 pages. Price $0.75.

INCLUDED in this single volume are the 11 American Standard Codes for the Prevention of Dust Explosions, a statement of fundamental principles of dust explosion prevention in industrial plants and a record of some 670 dust explosions which have occurred in the United States. The importance of the subject is indicated by the aggregate loss from these explosions which amounts to $1,600,000 and the death or injury of 94 persons.

GOVERNMENT PUBLICATIONS

Documents are available at prices indicated from Superintendent of Documents, Government Printing Office, Washington, D. C. Send cash or money order; stamps and personal checks not accepted. When no price is indicated, pamphlet is free and should be ordered from bureau responsible for its issue.

Trade Agreement Reports. The U. S. Tariff Commission is issuing a series of reports on industries affected by the trade agreements program. Those issued thus far are on: Tobacco and Tobacco Manufactures; Sugar; Fats, Oils, Waxes, and Oil-Bearing Materials; Glass and Glassware; Pottery; Dairy Products. Available on request from U. S. Tariff Commission, Washington, D. C.

Fumigation of Vetch Seed for the Vetch Bruchid, by A. C. Johnson, et al. U. S. Department of Agriculture. Circular No. 555; 5 cents.

The Peanut Industry, A Selected List of References on the Economic Aspects of the Industry, 1920–1939. Bureau of Agricultural Economics, Agricultural Economics Bibliography No. 80; mimeographed.

Reducing Dust Explosion Losses in Industrial Plants, by David J. Price. Address before Fire Prevention Session, 11th Annual Safety Convention, Greater New York Safety Council. Bureau of Agricultural Chemistry and Engineering, ACE-35; mimeographed.

Chemical and Mechanical Methods of Ribes Eradication in the White Pine Areas of the Western States, by H. R. Offord, G. R. Van Atta, and H. E. Swanson. U. S. Department of Agriculture, Technical Bulletin 692; 15 cents.

Two Rapid Methods for Estimating Fineness and Cross-Sectional Variability of Wool, by J. I. Hardy and H. W. Wolf. U. S. Department of Agriculture, Circular 543C; 5 cents.

Behavior of Boron in Soils, by Frank M. Eaton and L. V. Wilcox. U. S. Department of Agriculture, Technical Bulletin 696; 15 cents.

Chart Analysis of Federal Food, Drugs, and Cosmetic Act. A schematic presentation to facilitatate finding of significant sections of the law according to subject. Each section of the chart quotes the applicable text of the law. This chart is available for limited distribution only from the Consumers Standards Project, Consumers' Counsel Division, Agricultural Adjustment Administration, Washington, D. C.

Simultaneous Production of Wood Pulp and the Conversion of the Noncellulosic Constituents of Wood into Alcohols, Oils, and Resins, by Elwin E. Harris and E. C. Sherrard. Available from Forest Products Laboratory, U. S. Department of Agriculture, Madison, Wisconsin.

Hydrogenation of Lignin in Aqueous Solutions, by Elwin E. Harris, Jerome Saeman, and E. C. Sherrard. Available from Forest Products Laboratory, U. S. Department of Agriculture, Madison, Wisconsin.

Survey of Current Business, February 1940. This issue is the Annual Review Number, summarizing the changes which occurred in major fields of business during 1939. Bureau of Foreign and Domestic Commerce; 15 cents.

Investigation of Concentration of Economic Power, Part 10—Life Insurance. Hearings before Temporary National Economic Committee on life insurance, including intercompany agreements, terminations, savings bank insurance, and legislative activities.

Decisions and Orders of the National Labor Relations Board, Volume 14, August 1–31, 1939. National Labor Relations Board; $1.75 (cloth).

Written Trade Agreements in Collective Bargaining. National Labor Relations Board, Division of Economic Research, Bulletin No. 4; 35 cents.

Statistics on Whiskey, Rum, and Brandy, from January 1 to December 31, 1939. Federal Alcohol Administration, Treasury Department; mimeographed.

Regulations 106, relating to the employees' tax and the employers' tax under the Federal Insurance Contributions Act. Bureau of Internal Revenue, Treasury Department; 15 cents.

The Code of Federal Regulations of the U. S. A. Having General Applicability and Legal Effect in Force June 1, 1938. Volume 7—Title 26—Internal Revenue. This volume consists of two books, sold in sets only, at $4.50 per set (buckram).

Milk Ordinance and Code, Recommended by the United States Public Health Service 1939. U. S. Public Health Service, Bulletin No. 220 (1939 Edition); 35 cents.

Index of United States Army and Federal Specifications Used by the War Department. War Department; 25 cents.

Federal Specifications. EE-L-101a, Amendment 2, Lard Substitutes. TT-V-81a, Varnish; Mixing (for) Aluminum Paint. O-P-106, Paste; Linoleum. TT-P-156, Paint, white-lead-base; basic-carbonate, ready-mixed, light-tints and white. QQ-A-371a, Aluminum-alloy; ingots. These specifications are 5 cents each.

Motor Carrier Safety Regulations Governing the Transportation of Explosives and Other Dangerous Articles. Interstate Commerce Commission, Ex Parte No. M. C.-13. Published in Federal Register, April 23, 1940; 10 cents.

Performance Test of Floor Coverings for Use in Low-Cost Housing: Part 2, by Percy A. Sigler and Elmer A. Koerner. National Bureau of Standards, BMS Report 43; 10 cents.

Literature on Drycleaning. National Bureau of Standards, Letter Circular 583; mimeographed.

List of Commercial Standards, Revised to January 1, 1940. National Bureau of Standards, Letter Circular 579; mimeographed.

Ground and Polished Lenses for Sun Glasses. National Bureau of Standards, Commercial Standard CS78-39; 5 cents.

Heat of Fusion of Ice. A Revision, by Nathan S. Osborne. National Bureau of Standards, Research Paper 1260; 5 cents.

Railway Track Scale Testing Service of the National Bureau of Standards, Fiscal Year 1939. National Bureau of Standards, Letter Circular 580; mimeographed.

Annual Report of the Petroleum and Natural-Gas Division, Fiscal Year 1939, by R. A. Cattell and Others. Bureau of Mines, Report of Investigations 3501; mimeographed.

Annual Report of Research and Technologic Work on Coal, Fiscal Year 1939, by A. C. Fieldner and R. E. Brewer. Bureau of Mines, Information Circular 7105; mimeographed.

Hydrogenation and Petrography of Some Low-Rank Coals from the Western United States, by A. Eisner and others. Bureau of Mines, Report of Investigations 3498; mimeographed.

Combustibility of Coke in Air, by R. E. Zane and H. F. Yancey. Bureau of Mines, Report of Investigations 3499; mimeographed.

Application of Well-Test Data to the Study of a Specific Gas-Production Problem, by M. A. Schellhardt, E. J. Dewees, and W. H. Barlow. Bureau of Mines, Report of Investigations 3493; mimeographed.

List of Bulletins of the Agricultural Experiment Stations for the Calendar Years 1937 and 1938. By C. E. Pennington. All papers issued in the two years 1937 and 1938 are listed three ways; first by bulletins, second by authors and third is an index of subjects. Miscellaneous publication No. 362; 15 cents.

Effect of Fluorides on Salivary Amylase, by F. J. McClure, Public Health Service, reprint No. 2116; 5 cents.

Supplement to List of Publications Bureau of Mines, July 1, 1938 to June 30, 1939. A list of publications, together with author and subject indexes. Bureau of Mines unnumbered pamphlet.

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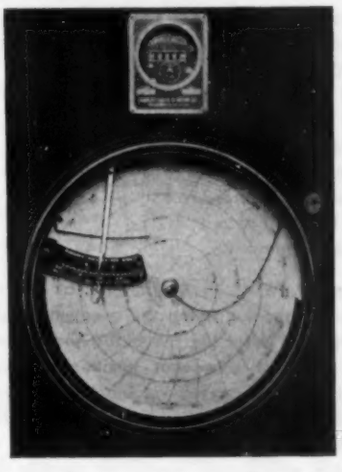

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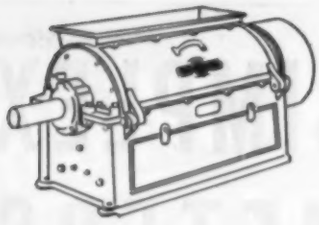

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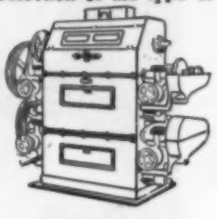

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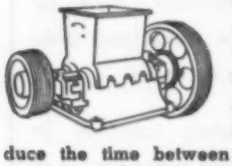

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MANUFACTURERS' LATEST PUBLICATIONS

Publications listed here are available from the manufacturers themselves, without cost unless a price is specifically mentioned. To limit the circulation of their literature to responsible engineers, production men and industrial executives, manufacturers usually specify that requests be made on business letterhead.

Bearings. Bantam Bearings Corp., South Bend, Ind.—Bulletin 104—24-page bulletin with engineering and application information on special bearings, including quill and needle bearings, ball and roller thrust bearings.

Bearings. Dodge Mfg. Corp., Mishawaka, Ind.—Bulletin A-325—18-page catalog describing this company's new Dodge-Timken Double-Interlock roller bearings, applied to pillow blocks and other bearing forms, complete with description and selection tables.

Bearings. Johnson Bronze Co., New Castle, Pa.—Catalog 400—76-page 1940 general catalog on this company's bronze sleeve bearings, bushings and bars; also babbitt, graphited bronze and self-lubricating bronze. Extensive section devoted to electric motor bearings.

Bearings. Advertising Dept., New Departure Div., General Motors Corp., Bristol, Conn.—112-page book entitled "Why Anti-Friction Bearings," presenting a readable impartial discussion relating to selection of anti-friction bearings, designed for engineering colleges and others needing this type of information.

Building Maintenance. Flexrock Co., 2312 Manning St., Philadelphia, Pa.—68-page "Handbook of Building Maintenance," second edition, giving information on maintenance of floors, walls, roofs and other building elements.

Castings. Thomas Foundries, Inc., Birmingham, Ala.—4 pages describing Ni-Hard and Ni-Resist castings produced by this company.

Centrifugals. American Tool & Machine Co., 1415 Hyde Park Ave., Boston, Mass.—8-page bulletin describing various types of centrifugal separator made by this company, with information on various specialized applications of centrifugals in chemical processes.

Chemicals. Glyco Products Co., 148 Lafayette St., New York City—96-page 1940 edition of "Chemicals by Glyco," describing glycol and glyceryl esters, emulsifying agents, special emulsions, synthetic waxes and resins and a number of specialties.

Chemicals. Pennsalt Cleaner Div., Pennsylvania Salt Mfg. Co., 1000 Widener Bldg., Philadelphia, Pa.—Leaflet describing this company's Pennsalt concentrated alkaline cleaners for industrial use for removal of dirt, oils, paint, etc.

Cleaning. Magnus Chemical Co., Garwood, N. J.—35-page book on cleaning of industrial and other buildings, discussed on a case-study basis.

Condensers. Ingersoll-Rand Co., 11 Broadway, New York City—Form 2622—Describes Type R cross-flow surface condensers for high vacuum in small capacity ranges.

Dialysis. Brosites Machine Co., 30 Church St., New York, N. Y.—8-page booklet describing the Webcell continuous laboratory model dialyzer, made of Lucite to permit visual operation.

Dust Collectors. American Air Filter Co., Louisville, Ky.—Bulletin 270—12-page booklet on this company's Roto-Clone dust collector, particularly from the standpoint of numerous applications.

Electrical Equipment. General Electric Co., Schenectady, N. Y.—Publications as follows: GEA-1412B, 1368D, 3223, describing a variety of vertical motors; GEA-2742A, Pyranol low-voltage industrial capacitors; GEA-214D, 1157C, 1265D, 2592A, 2618A, and 104B, bulletins devoted to electric heaters and thermostatic controls, including immersion, strip, space and finned electric heating units; GEA-2902B, vacuum tube time delay relays; GEA-3345, synchronous motors; GES-2285, voltage regulators; Y-072, 4 pages on drying lamps.

Electrical Equipment. Westinghouse Electric & Mfg. Co., Dept. 7-N-20, East Pittsburgh, Pa.—Publications as follows: Catalog 30-000, 64-page quick-selector catalog on apparatus for motor, lighting and feeder circuits; booklet 32-100, metal inclosed switchgear; DD 3113, repulsion-induction motors; DD 29-530, De-ion circuit breakers; DD 49-120, dust-tight capacitors.

Equipment. Bethlehem Foundry & Machine Co., Bethlehem, Pa.—44-page catalog of this company's process equipment, including Thermocoil equipment for steam and diphenyl heating; nitrators; reducers; sulphonators; mixing kettles; vacuum stills; retorts; autoclaves; acid eggs; and production and experimental roasters. Also gives a group of typical *Chem. & Met.* Flow Sheets, modified to show use of this company's equipment.

Equipment. Birmingham Tank Co., Birmingham, Ala.—6-page leaflet illustrating and describing a variety of steel plate work fabricated by this company, including rotary dryers, stacks, tanks, diffusers, etc.

Equipment. S. Blickman, Inc., Weehawken, N. J.—4-page leaflet, briefly describing types of industrial equipment made by this company for process industry use, including evaporators, stills, kettles and pressure vessels.

Equipment. Cochrane Corp., 17th and Allegheny Ave., Philadelphia, Pa.—Publication 2960—Leaflet describes this company's exhaust head for separating condensate and oil from steam discharged to the atmosphere.

Equipment. DeLaval Steam Turbine Co., Trenton, N. J.—Catalog F—52 pages on centrifugal blowers and compressors, with information on applications, design and construction, methods of control and drives, and an extensive technical data section on the principles of compression of gases. Also reprint of an article by F. S. Broadhurst, describing this company's new automatic priming system for centrifugal pumps.

Equipment. Dorex Div., The W. B. Connor Engineering Corp., 114 East 32d St., New York City—New catalog on this company's odor absorbing equipment, employing activated carbon.

Equipment. The Dorr Co., 570 Lexington Ave., New York City—Bulletin 5001—8 pages describing this company's new Type V diaphragm pump, featuring adjustability during operation, low headroom and moderate pressure lifts. Also 12-page pictorial review of this company's manufacturing methods.

Equipment. First Machinery Corp., East 9th St. and East River Drive, New York City—6-page newspaper-type bulletin entitled "First Facts," describing a wide variety of new and used equipment offered by this company.

Equipment. The Jeffrey Mfg. Co., Columbus, Ohio.—Booklet 733—32-pages describing pictorially the wide line of equipment made by this company and its subsidiaries, including power transmission, materials handling and pulverizing equipment, mine equipment and road machinery.

Equipment. The Logan Engineering Co., 4912 Lawrence Ave., Chicago, Ill.—Bulletin 340—4 pages describing this company's Aridifier for removing moisture, dirt and oil from compressed air and gas, by centrifugal action.

Equipment. The Steel Improvement & Forge Co., Cleveland, Ohio—"Boiler and Tank Accessories," a complete catalog

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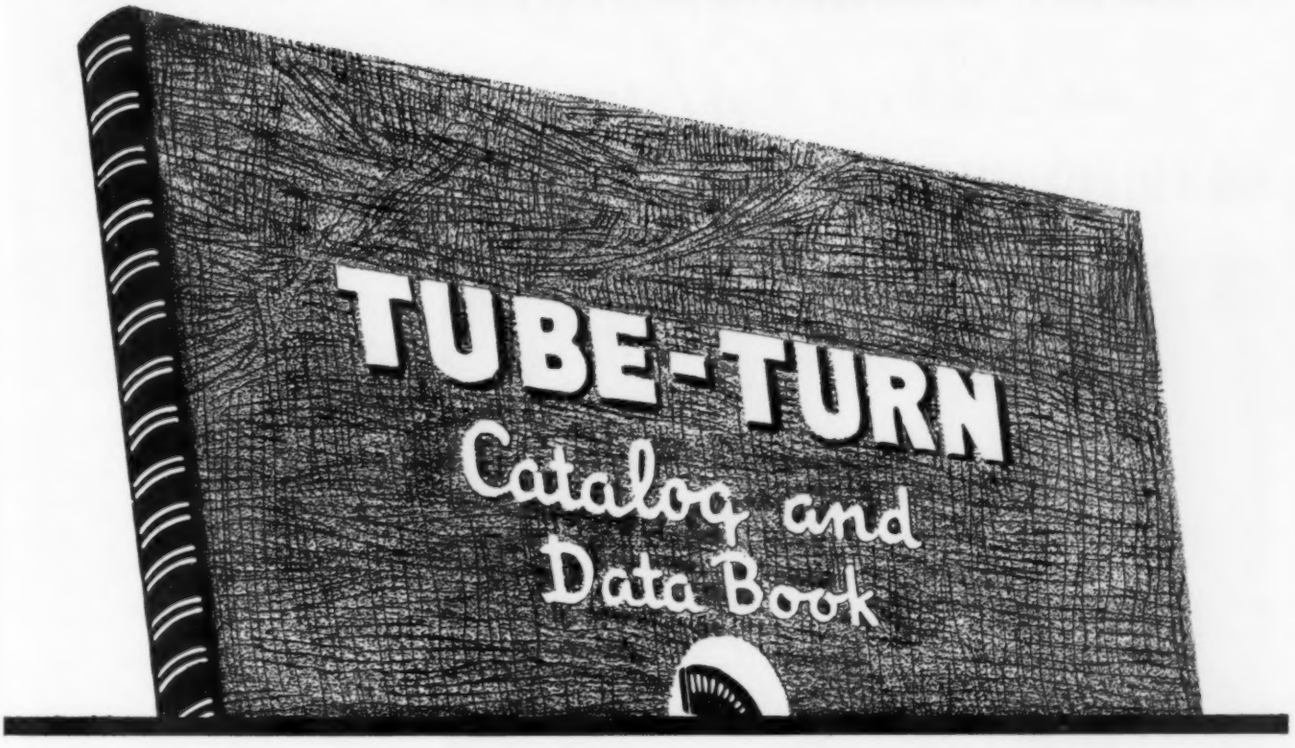

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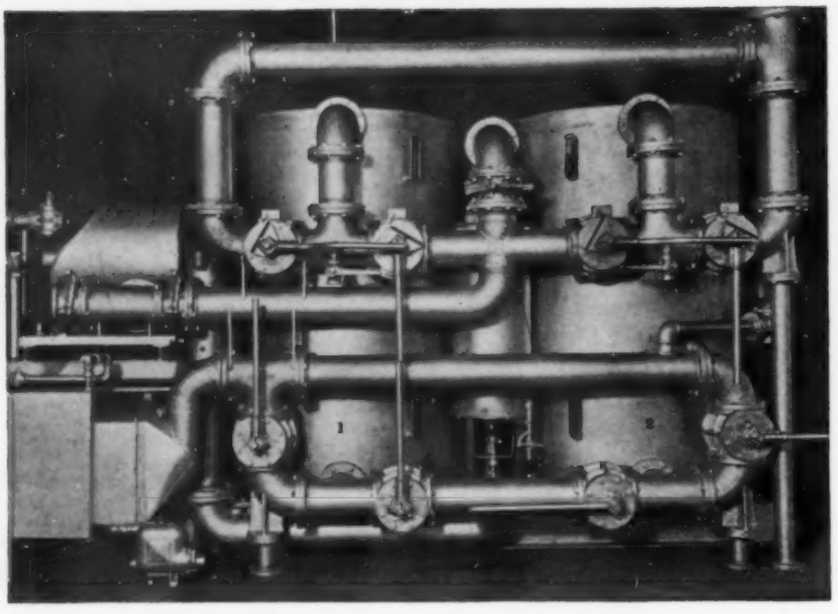

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Fans. DeBothezat Ventilating Equipment Div., American Machine & Metals, Inc., East Moline, Ill.—12-page catalog describing this company's "Bifurcator" ducts-mounted disk fan, with dimension and performance information; also 24-page catalog on other types of axial flow disk fans made by this company, with selection and performance information.

Humidifiers. Armstrong Machine Works, Three Rivers, Mich.—Form 130—4 pages describing a new unit steam humidifier recently announced by this company. Table gives steam requirements for humidification under various circumstances.

Instruments. The Bristol Co., Waterbury, Conn.—Bulletin 540—Describes this company's pressure-volume-time-temperature recorder for gas, for application to rotary displacement meters.

Instruments. The Esterline Angus Co., Indianapolis, Ind.—Bulletin 939—4 pages on a variety of applications of the graphic wattmeter.

Instruments. Republic Flow Meters Co., 2240 Diversey Parkway, Chicago, Ill.—Data Book S-21—90-page book on this company's automatic combustion control equipment as applied to all sizes of boiler and all types of fuel-firing equipment. Describes automatic combustion control, equipment for its use, and also gives numerous detailed reports of actual installations classified by firing methods.

Instruments. F. J. Stokes Machine Co., Tabor Road, Olney P. O., Philadelphia, Pa.—6-page leaflet on this company's portable McLeod gage for high vacuum measurements in plant and laboratory.

Metals and Alloys. International Nickel Co., 67 Wall St., New York City—12-page booklet describing properties of various nickel alloys including Monel, K Monel, R Monel, nickel, Z nickel, Inconel and S Monel castings.

Metal Spray. Master Metal Spray, Inc., 2527 Magnolia St., Oakland, Calif.—4-page leaflet describing this company's new Speedmaster metal spray gun.

Microscopes. Spencer Lens Co., Buffalo, N. Y.—16-page catalog describing a new line of stereoscopic microscopes featuring new mechanical improvements and available in four different arrangements, recently announced.

Mixing. Patterson Foundry & Machine Co., East Liverpool, Ohio—Leaflet describing this company's conical blender for dry materials.

Paints. The Skybryte Co., 3125 Perkins Ave., Cleveland, Ohio—Catalog 8—16-page book describing this company's range of paints and materials for building maintenance, including heat- and acid-resisting paints, concrete and stone paints, and various other regular and special paints.

Plastics. Carbide & Carbon Chemicals Corp., 30 East 42d St., New York City—18-page pamphlet on fabricating processes for Vinylite resins with information on properties, molding and finishing.

Power Transmission. Boston Gear Works, North Quincy, Mass.—General Catalog 53—290-page 1940 edition on this company's power transmission equipment, giving specifications and list prices on stock gears, chain and sprockets, motorized and non-motorized speed reducers, couplings, universal joints and line shaft accessories. Facilitates application calculations.

Pumps. Fairbanks, Morse & Co., 600 South Michigan Ave., Chicago, Ill.—Bulletin 5972—6 pages on this company's two-stage split-case centrifugal pumps for capacities to 550 g.p.m. at heads ranging up to 600 ft. total discharge head.

Pumps. Roots-Connersville Blower Corp., Turbine Pump Div., Connersville, Ind.—Bulletin 260-B15—4 pages describ-

ing and giving data on a small centrifugal-type jet deep-well pump for below-ground heads to 120 ft.

Rope Clips. Thomas Laughlin Co., Portland, Maine—4-page leaflet describing a new safety clip for wire rope, claimed to be easier to use and not to damage the rope.

Rubber Putty. The B. F. Goodrich Co., Akron, Ohio—New catalog section on this company's Plastikon rubber putty for luting and sealing against the elements and also against corrosive chemicals.

Safety Equipment. The Boyer-Campbell Co., 6540 Antoine St., Detroit, Mich.—Catalog 40—136-page catalog entitled "Everything for Safety," on eye, face and head protection, machine guards, safety clothing and other equipment.

Screens. The Orville Simpson Co., Cincinnati, Ohio—Bulletin 401—4 pages describing this company's line of Rotex gyratory screeners.

Soaps. The Warwick Chemical Co., West Warwick, R. I.—New technical bulletin on metallic soaps and their uses.

Tanks. The Hauser-Stander Tank Co., Cincinnati, Ohio—Catalog No. 40—100 pages of description and data on this company's wood tanks, agitator drives, special linings and accessories, with data section on properties and corrosion resistance of woods.

Traps. W. H. Nicholson & Co., Wilkes-Barre, Pa.—Catalog 240—18 pages on this company's steam traps in thermostatic, expansion, weight-operated and piston-operated designs, with engineering and application data.

Traps. Wright Austin Co., 315 West Woodbridge St., Detroit, Mich.—Circular 265—2-page leaflet describing a new float trap for the draining of compressed air lines.

Tube Fabrication. The Parker Appliance Co., 17325 Euclid Ave., Cleveland, Ohio—Bulletin 40E—34-page price list, discussion and instruction book on this company's pipe and tube bending and flaring equipment.

Valves. Bartlett Hayward Div., Koppers Co., Baltimore, Md.—Bulletin 808—4 pages describing Type AR all-iron gate valves in sizes from 5 to 48 in.

Valves. Crane Co., Chicago, Ill.—Form AD 1420—12 pages on small steel valves made in gate, globe, angle and check types in sizes to 2 in.

Valves. Hancock Valve Div., Manning, Maxwell & Moore, Inc., Bridgeport, Conn.—Bulletin 5-7000—40-page book on this company's steel valves, giving material specifications of all metals used and complete dimensions on all types.

Vessel Heads. Lukens Steel Co., Coatesville, Pa. Catalog No. 1—"Lukens Flanging and Pressing," — 131-page spiral-bound book on spun heads for pressure vessels and other chemical process equipment, containing considerable data never before published. Describes forming methods, all principal types of spun heads, gives list prices for forming, information on hand-holes and man-holes; includes numerous tables of useful information.

Waste Treatment. Monsanto Chemical Co., St. Louis, Mo.—16-page book entitled "Ferrisul," devoted to the use of anhydrous ferric sulphate in the treatment of water, sewage and industrial wastes.

Welding. Metal & Thermit Corp., 120 Broadway, New York City—Vol. 1, No. 1, of a new periodical leaflet entitled "Welding Briefs," devoted principally to interesting industrial applications of electric arc welding.

Welding. Wilson Welder & Metals Co., 60 East 42d St., New York City—Booklet ADW-18—24 pages on this company's arc welding electrodes, designed for easy selection for all classes of work.

X-Ray Data. St. John X-ray Service, Inc., 30-20 Thomson Ave., Long Island City, N. Y.—4-page leaflet of data relating to X-ray work, given for the 92 elements.

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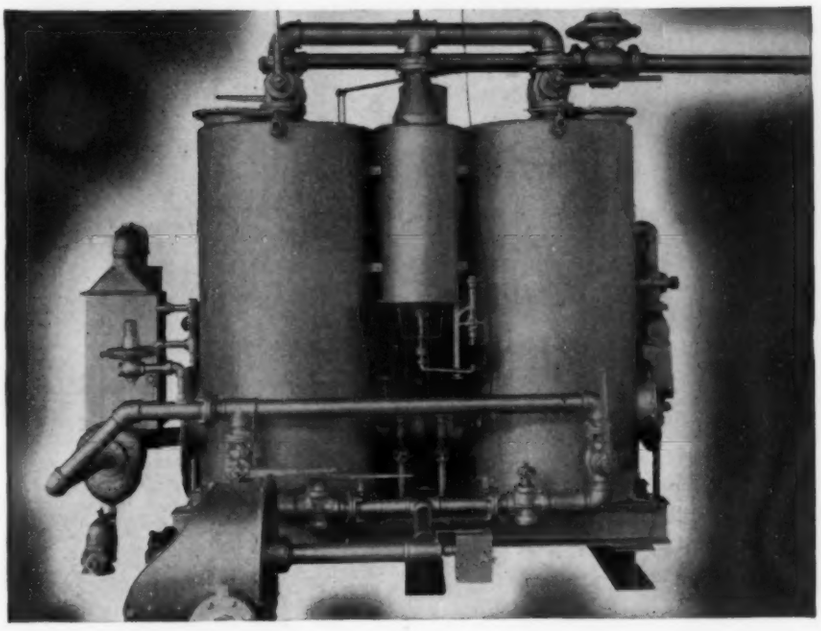


You can depend on Kemp Adsorptive dryers for dehydration of gases and air to any required degree down to the commercial absolute, -76° C.

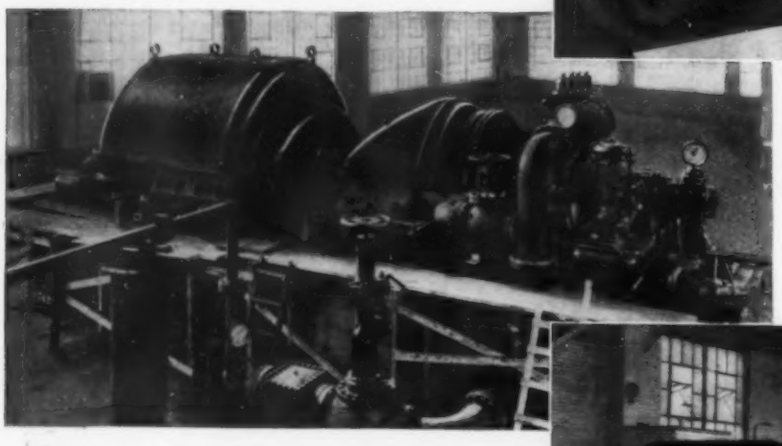
Available with single or twin towers for intermittent or continuous operation, standard Kemp units are built from 10 to 100,000 c. f. per minute capacity to operate at pressure from atmospheric to 2,500 pounds per square inch. Activation of the Silica Gel is accomplished by gas, electricity, or steam as desired.

Already well established in the Chemical, Steel, and Food Industries, Kemp Adsorptive Dryers live up to the 62 year performance record of Kemp Equipment. For a new Dryer Bulletin giving further details, address **The C. M. Kemp Mfg. Co., 405 East Oliver Street, Baltimore, Md.**

KEMP of BALTIMORE

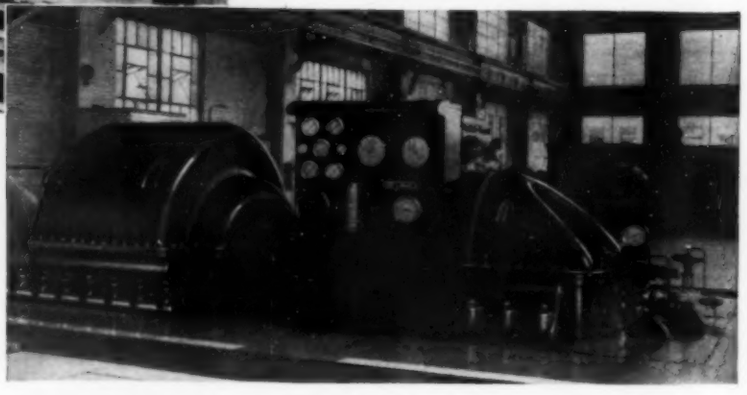
BLOWERS *for* LARGE VOLUMES

At right—Turbine-driven blast furnace blower; 85,000 cu. ft. per min. against 30 lb. at 2800 r.p.m. The turbine receives steam at 400 lb. gage and 700° F. and exhausts to a 28 in. vacuum. The governor holds the oxygen supply to the furnace constant, compensating automatically for variations in atmospheric pressure and temperature.



Below—Turbine-driven blast furnace blower to deliver 75,000 cu. ft. per min. of free air at 60° F. against 30 lb. gage at 3000 r.p.m.

Above—Turbine-driven blast furnace blower on test at De Laval Works; 115,000 cu. ft. per min. of free air against 30 lb. pressure.



DE LAVAL BLOWERS, COMPRESSORS AND EXHAUSTERS

are built in all capacities required and for pressures up to 100 lb. per sq. in.

The 115,000 cu. ft. blast furnace blower shown herewith is believed to be the largest yet built. The 85,000 cu. ft. unit, a repeat order, is installed with the 75,000 cu. ft. unit, which has given highly satisfactory service for the past three years.

State your requirements so that our engineers may submit data on efficiencies and cost, together with catalog describing our most recent designs.

3814

DE LAVAL STEAM TURBINE CO. · TRENTON, N. J.

SEASONAL INFLUENCES WORKED AGAINST CONSUMPTION OF CHEMICALS IN APRIL

Chem & Met ECONOMICS and MARKETS

CONSUMPTION of sulphuric acid in the manufacture of superphosphates carries a heavy weighting in any consideration of total chemicals used within a given period. In the first quarter of last year, consumption of acid in that direction ran slightly over 500,000 tons expressed in terms of 50 degree acid. In the first quarter of this year such consumption exceeded 600,000 tons. From April forward production of superphosphate normally declines. From trade reports this seasonal influence was felt last month. Unfavorable weather conditions served to slow up demand for paints and different other products for which April usually brings a seasonal uplift. Hence seasonal influences, normal and reversed, have worked against manufacturing call for chemicals.

Data at hand places the index for chemical consumption in April at 125

Chem. & Met. Index for Consumption of Chemicals

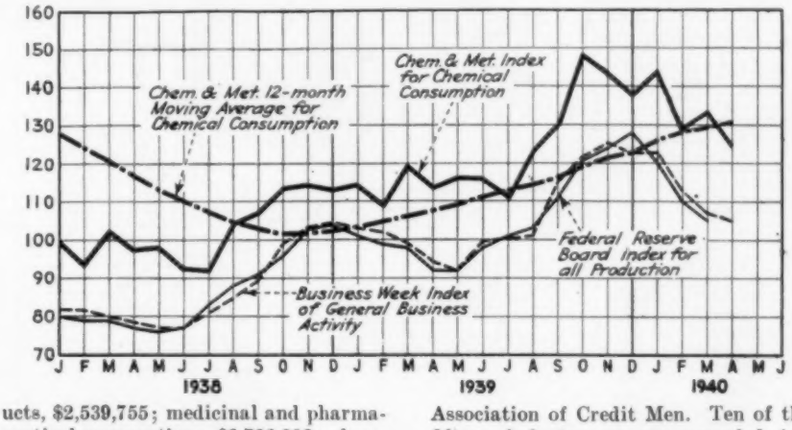
	February	March
Fertilizer	28.14	27.70
Pulp and paper	17.83	18.28
Glass	11.94	13.20
Petroleum refining	13.26	13.55
Paint and varnish	8.60	10.27
Iron and steel	8.73	8.57
Rayon	10.93	11.17
Textiles	8.33	7.82
Coal products	8.04	8.36
Leather	3.72	3.79
Explosives	4.53	4.41
Rubber	3.07	3.09
Plastics	2.57	2.64
	129.69	132.76

which compares with a revised index of 132.76 for March and with 113.91 for April 1939. With the exception of the paint and varnish industry, declines in the rate of operation was reported for the major consuming plants. Some branches of pulp and paper also were reported to have made a favorable showing. The decline in textile production was checked in the latter part of April although silk plants have shown no signs of improvement. Latest reports credit a rise in steel outputs but the downward trend extended through April. Rayon mills have held a fairly steady program with staple production becoming increasingly important as further plant capacity came into action in February.

Many chemical plants continue to operate at capacity with outputs passing directly to consumers; others have held unchanged schedules in order to build up a normal surplus of unsold stocks. Export inquiry has kept considerably above normal and continues to be important in influencing production schedules.

The position of the chemical industry may be better understood by giving consideration to export trade as well as to domestic consumption. With the release of detailed figures by the Department of Commerce, it is found that outward shipments of chemicals and related products for the first three months of this year carried a valuation of $52,717,000 as compared with $31,427,000 for the corresponding period of last year. In other words our foreign trade this year has exceeded that for 1939 by nearly 68 per cent.

According to the Monthly Summary of Foreign Commerce, exports of chemicals and related products as included under Group 8 amounted to $18,780,000 in March as against $12,553,000 in March last year. Details for the various divisions were: coal-tar products, $2,539,755; medicinal and pharmaceutical preparations, $2,722,292; chemical specialties, $3,802,233; industrial chemicals, $4,467,353; pigments, paints, and varnishes, $2,625,463; fertilizers and fertilizer materials, $884,283; explosives, fuses, etc., $914,168; soap, $276,733; and toilet preparations, $547,602.


160
150
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70
Chem. & Met. Index for Chemical Consumption
Chem. & Met. 12-month Moving Average for Chemical Consumption
Federal Reserve Board Index for all Production
Business Week Index of General Business Activity
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J
1938
1939
1940

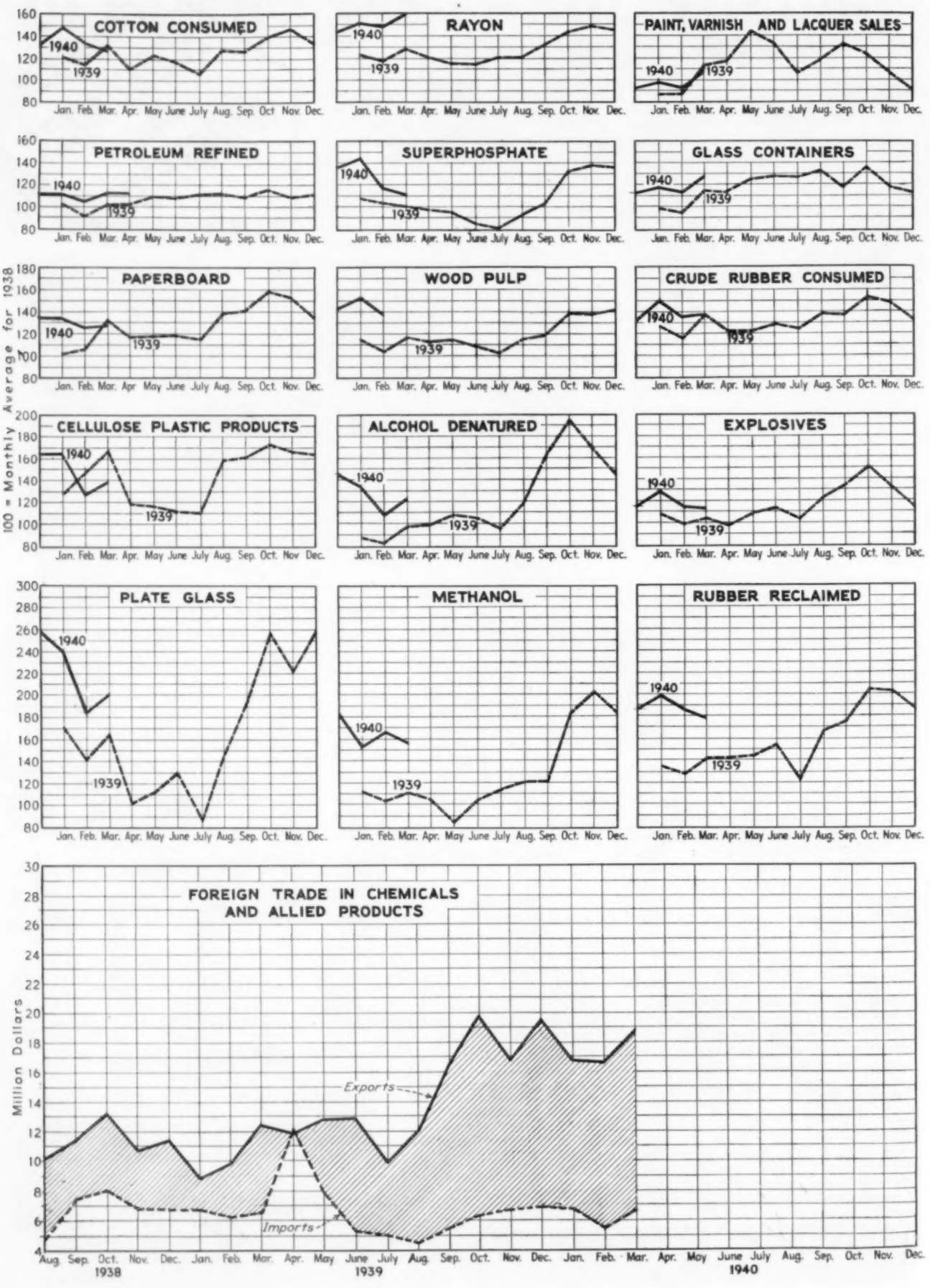
Sales of manufacturers in March were 7 per cent higher than those reported for March last year according to data compiled by the Bureau of the Census in cooperation with the National Association of Credit Men. Ten of the fifteen industry groups recorded improved sales conditions while four reported losses and one showed no change from March 1939. For chemicals and allied products, sales were given as 6.6 per cent higher than in February and unchanged from those of March last year.

Production and Consumption Data for Chemical-Consuming Industries

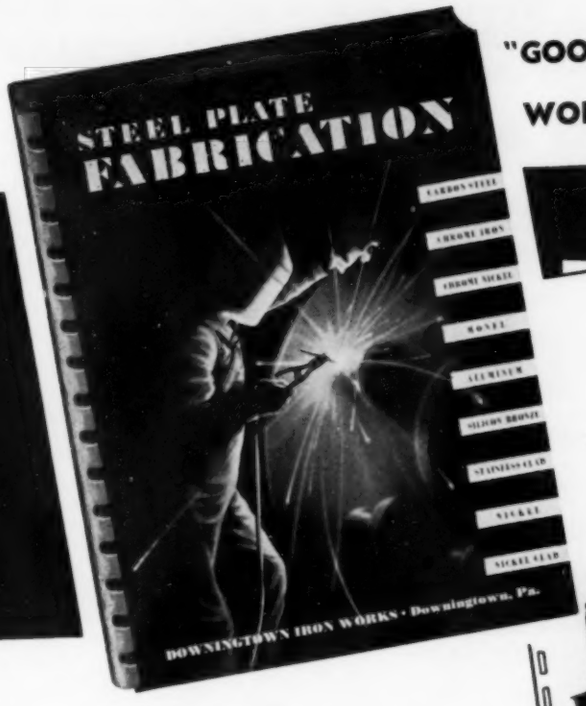
	March 1940	March 1939	January-March 1940	January-March 1939	Per cent of gain for 1940
PRODUCTION					
Alcohol, ethyl, 1,000 pr. gal.	20,983	17,438	62,020	49,155	26.2
Alcohol denatured, 1,000 wi. gal.	9,524	7,616	28,382	20,889	35.9
Ammonia, liquor, 1,000 lb.	4,504	4,034	13,845	11,539	20.0
Ammonium sulphate, tons	56,059	46,670	169,926	134,206	26.6
Automobiles, sales	423,299	371,946	1,259,027	1,017,334	23.8
Benzol, 1,000 gal.	9,952	8,063	31,071	22,992	35.1
Byproduct coke, 1,000 tons	4,125	3,439	12,849	9,883	30.0
Glass containers, 1,000 gr.	4,606	4,125	12,992	11,096	17.1
Plate glass, 1,000 sq. ft.	14,302	11,867	44,734	34,241	30.6
Window glass, 1,000 boxes	1,107	912	3,619	2,664	35.8
Methanol, crude, 1,000 gal.	507	365	1,411	1,052	34.1
Methanol, syn. 1,000 gal.	3,463	2,407	10,698	7,137	49.9
Nitrocellulose plastics, 1,000 lb.	1,090	1,315	3,345	3,287	1.8
Cellulose acetate plastics, 1,000 lb.					
Sheets, rods, and tubes	550	1,078	2,044	2,962	31.0*
Molding composition	1,104	963	3,253	2,560	27.1
Rubber reclaimed, tons	18,266	14,528	57,773	41,384	39.6
Steel barrels and drums, heavy	851,912	737,155	2,792,415	2,120,699	31.7
Steel barrels and drums, light	218,745	215,209	671,364	536,661	25.1
CONSUMPTION					
Cotton, bales	626,331	649,940	2,019,133	1,810,652	11.5
Silk, bales	21,685	37,863	73,676	111,898	34.1*
Wool, 1,000 lb.	25,049	30,966	92,901	97,916	5.1*
Explosives, 1,000 lb.	30,189	27,801	95,914	83,651	14.7
Paint and varnish, sales, $1,000	31,592	32,888	86,796	83,454	4.1
Rubber reclaimed, tons	17,560	15,322	52,265	40,948	27.6

* Per cent of decline.

Production and Consumption Trends

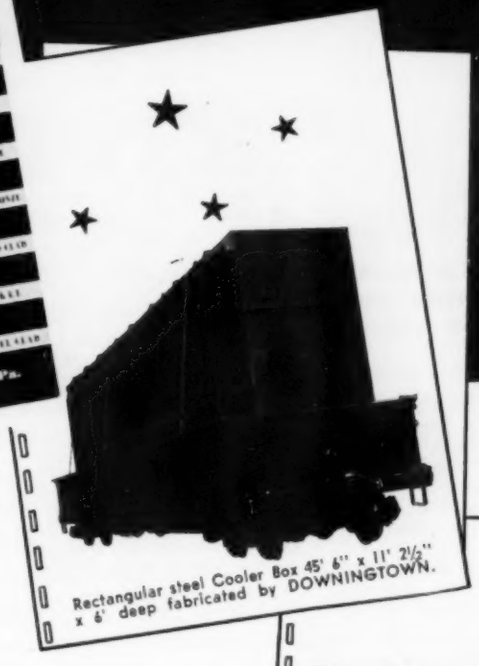


"GOOD DESIGN – RIGHT MATERIALS – EXPERT WORKMANSHIP–GOOD SERVICE–FAIR PRICE"

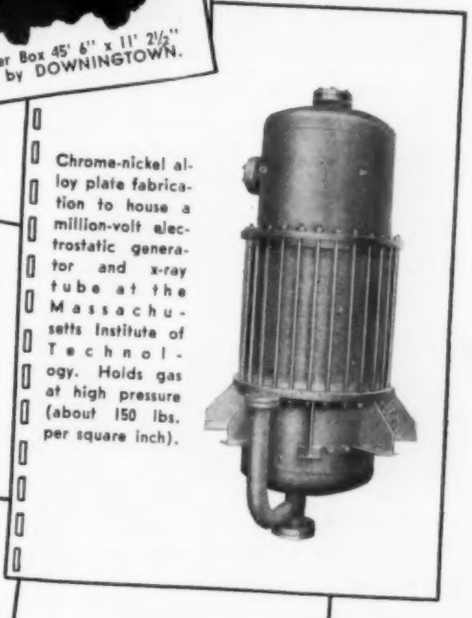


Do you have your FREE COPY of this NEW 42-PAGE REFERENCE BOOK? It highlights A.S.M.E. regulations . . . gives valuable reference data . . . fully illustrates and describes Downingtown's modern facilities and experience in plate fabrication. Just send a note on your letterhead to have all this at your fingertips.

DOWNINGTOWN IRON WORKS
DOWNINGTOWN PENNSYLVANIA



Rectangular steel Cooler Box 45' 6" x 11' 2½" x 6' deep fabricated by DOWNINGTOWN.



Chrome-nickel alloy plate fabrication to house a million-volt electrostatic generator and x-ray tube at the Massachusetts Institute of Technology. Holds gas at high pressure (about 150 lbs. per square inch).

Concentrator, 12' x 16' 6".

★ One of six tanks fabricated with ⅜" shell plates and ½" heads from Everdur (1010). Carbon—arc welded.

A DOWNINGTOWN fabrication —10' diameter, 18' 6" overall length—material of chrome 18% and nickel 8%.

1940
TWENTY-FIFTH ANNIVERSARY OF SERVICE TO THE CHEMICAL INDUSTRIES

Stearns MAGNETIC

SEPARATORS • DRUMS • ROLLS
CLUTCHES • BRAKES • MAGNETS

WILL HELP GIVE YOU MORE PROFITABLE PRODUCTION WITH BETTER ENGINEERED MAGNETIC PRODUCTS.

STEARNS Magnetic Pulleys, improved, air-cooled, powerful—for protection, purification or concentration—wide range of sizes or complete separator units. Bulletin 301.

STEARNS Type "K" High Intensity Magnetic Separators for high concentration of ores, separating highly reluctant material—can be designed in multiple magnetic zones to suit type of separation and capacity. Bulletin 700.

STEARNS automatic drum-type fully enclosed magnetic separator, fast, positive protection against tramp iron in grinders, crushers and pulverizers. Bulletin 93-B.

For separating liquids or material in solution containing impurities this Stearns Type "QS" Automatic Magnetic Filter will reduce your rejects. Ceramic folder.

STEARNS Suspended magnets, circular, rectangular and other shapes and all sizes. Our Bulletin 25-B describes fully.

We will be glad to test your material, 25 to 50 lbs. prepaid for analysis and recommendation.

STEARNS MAGNETIC MANUFACTURING CO.
629 S. 28th St. Milwaukee, Wis.

DOMESTIC PRODUCTION OF CHEMICALS INCREASED BY CHANGES IN FOREIGN TRADE

WITH several of the important consuming industries cutting down activities in April, demand for chemicals was affected accordingly and while the industry has maintained a level appreciably higher than was in effect a year ago, it has not kept up the pace which marked activities in the earlier part of the year. In the latter part of April, more favorable reports were heard regarding the textile, paint and varnish, steel, and paper trades. Shipping instructions for deliveries against May contracts came to hand in large volume and the month got underway with the promise that some uplift was in progress.

Production of chemicals continued to run ahead of the rate of domestic consumption aided partly by the call from foreign countries and partly by the fact that stocks at producing points had been practically non-existent at the beginning of the year and there was desire on the part of manufacturers to build up inventories to a more normal basis.

Prices for chemicals have shown no definite trend toward wide fluctuations in either direction. Contract prices for delivery over the second quarter were slightly higher in some cases but generally unchanged from those which prevailed for Jan.-March shipments. Trading in the spot market, however, has indicated that a strong undertone has existed and sales of many selections for export, and in certain cases for domestic account, have been made at prices above the openly quoted contract levels.

Prices for oils and fats have been affected by different influences. Oils of foreign origin have felt the effects of disturbed shipping conditions, higher ocean freights and increased insurance rates. At present the shipping situation is quite involved and values for palm, palm-kernel, olive, and China wood oils are more or less nominal. Domestic oils were firmer at the close of the period and tallow also has recovered from its lowest price level.

Export inquiry for chemicals is still important although the volume of inquiries is not as large as it was in the latter part of last year. Producers have kept export buying from unsettling domestic markets by maintaining control over stocks and thus holding speculative trading to a minimum. A large volume of business for export is going through, nevertheless, and is restricted in some cases by lack of goods to fill all export inquiries. Hence export trade has been a factor in extending domestic production. The situation abroad likewise has influenced domestic production by the cutting down or elimination of certain imports. For instance, home producers have been called upon to step up outputs to take care of call for such items as salt cake, caustic potash, chlorate of potash, and some of the coal-tar intermediates. In this connection it is of interest to note that imports of salt cake in March amounted to 13,987 tons although imports for the first quarter were only 33,352 tons.

To make up for the loss in imported chemicals, home producers not only have increased their usual outputs but new production has become noteworthy. New production of chlorate of potash and sulphate of potash has started since the outbreak of the war. A new plant for the manufacture of bichromates has been announced for Delaware. There are rumors that new production of bichromates also may be undertaken in the mid-west. Another announcement says that one of the potash producers is ready to enter the market with offerings of caustic potash, chlorate of potash, and possibly carbonate of potash. These are typical cases where lack of foreign-made chemicals has brought about enlarged production at home.

Imports of chemicals and related products in March were valued at $6,681,000 and included some selections which have been in limited supply. Imports included 1,917,564 lb. of argols; 1,169,050 lb. of chlorate and perchlorate of potash; 4,537,417 lb. of cyanide of soda; and 6,920 tons of sulphate of ammonia.

Acetic acid has practically dropped from import trade with only 90 lb. coming in during the first quarter of this year. No imports of tartaric acid were recorded for the quarter and the same holds true for copper sulphate, cream of tartar, potassium cyanide, nitrite and phosphate of soda.

For the first three months of the year exports were valued at $52,717,000 compared with $31,427,000 for the three-month period of last year. This means

CHEM. & MET.

Weighted Index of

CHEMICAL PRICES

Base = 100 for 1937

This month	**98.71**
Last month	98.65
May, 1939	97.27
May, 1938	100.24

The greater part of current chemical movement is against contracts for which prices have been fixed for second quarter deliveries. Some spot trading is going through at prices above the open quotations.

that exports this year have run close to 68 per cent ahead of those of last year. In the coal-tar division dyes, colors and stains show a marked increase in the export trade, with shipments in the past quarter amounting to 7,841,345 lb. as against 2,127,730 lb. in 1939. Toluol was not listed separately in the returns for last year but in the first quarter of this year, exports were 12,601,654 lb. In the chemical specialties division, copper sulphate is prominent because of its increased movement out of the country, the three-month totals being 12,705,260 lb. and 4,940,980 lb. respectively. Industrial chemicals have had an important part in foreign trade with increases fairly general. In the first quarter of last year, exports of acetic acid amounted to 33,048 lb. while in the like period of this year, exports were 2,303,782 lb. Acetone which has been a growing factor in export trade gained more rapidly this year with exports for the quarters being 7,106,174 lb. and 3,793,549 lb. respectively. Methanol was not shipped out of the country in a large way early last year but this year 923,796 gal. went out in the quarter. Foreign buying of sodium products has been large with a total of 158,856,851 lb. for this year and 121,093,691 lb. for last year. Borate offers an exception to the rule with a rather sharp drop in exports. Caustic figures are 58,433,341 lb. and 42,459,126 lb. Ash shipments were 33,664,171 lb. and 21,048,465 lb. Bichromate and chromate jumped from 1,457,103 lb. last year to 6,753,532 lb. this year.

The National Fertilizer Association reports that tag sales for fertilizer amounted to 1,183,000 tons for April which represents a decline of 7 per cent compared with sales for April last year. For the first four months of the year sales have reached a total of 3,999,574 tons as compared with 3,993,587 tons for the comparable period of 1939. While economic conditions have generally been favorable for an increase in fertilizer tonnage, the decline in tobacco acreage in some of the southern states appears to have been a factor in holding sales to a relatively low level. The drop in tobacco acreage also served to cut down demand for sulphate of potash.

CHEM. & MET.

Weighted Index of Prices for

OILS AND FATS

Base = 100 for 1937

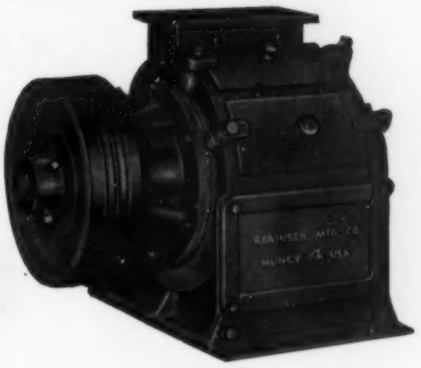
This month	78.88
Last month	78.06
May, 1939	70.85
May, 1938	76.79

Uncertainty about shipments has placed palm, palm-kernel, and olive oils in a more or less nominal position. Linseed oil failed to hold higher prices and other domestic oils are firmer. Tallow also has moved up in price.

You'll get plenty of ACTION—

WITH THIS NEW

KNIFE CUTTER



HERE is a new and decidedly better machine—the sturdiest, most compact and efficient Knife Cutter ever offered the Chemical and Process Industries.

Outstanding among its unique features is the removable cover plate which has been placed in front of each stationary knife. This easily-removed cover plate allows the operator to inspect and adjust the clearance between the revolving and stationary blades while they are in their proper cutting position.

This new knife cutter is readily adaptable to cutting, grinding, cracking, granulating, flocking, defiberizing and shredding a wide variety of plastic, tough or fibrous materials.

. . . Just one of the many high-speed production machines we build for the Chemical and Process Industries.

What Operation do you want to Improve?

GRINDING
CRUSHING
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PULVERIZING
BAG CLEANING
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Kindly send particulars on your equipment

for ..... (process) ..... (material)

Name .....

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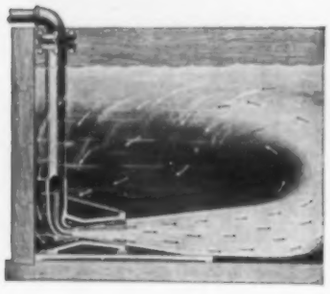
DURIRON Equipment for heating corrosive solutions

Duriron Steam Jets



Used to heat corrosive solutions by injecting steam directly into the solution. They are made in two types—floor and wall—with different sized orifices for various capacities.

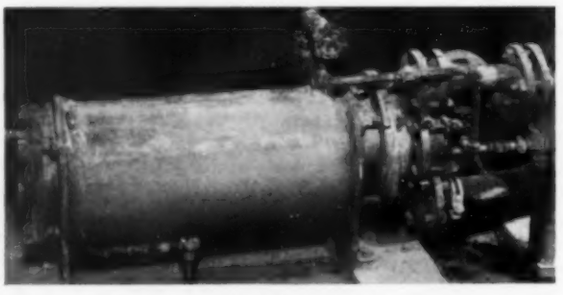
Steem jets are used to dissolve salts and dyes, to heat and circulate metal pickling solutions and to promote the absorption of gases in liquids.

Corrosive solutions can be heated with Duriron equipment by these methods: Direct Heating with Duriron Steam Jets, and Indirect Heating, applied either internally or externally.

Internal heating units, such as Duriron coils and immersion heaters, are useful where dilution is not permissible in the solution.

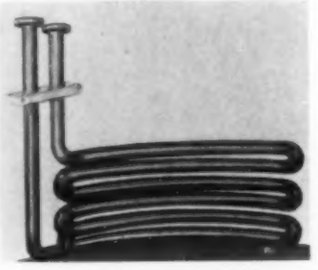
External heating units — Duriron Heat Exchangers — are used extensively in the heating of cleaning and plating solutions. Installations of two sizes of Duriron Heat Exchangers are shown below.

If you have a problem in the heating of a corrosive solution, it may be solved by the use of either standard or special Duriron Equipment. We shall be glad to assist you.

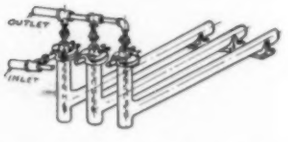


Duriron No. 6-025 Heat Exchanger, including pump not shown, handling a plating solution in plant of Ames Plating Co., Chicopee, Mass.

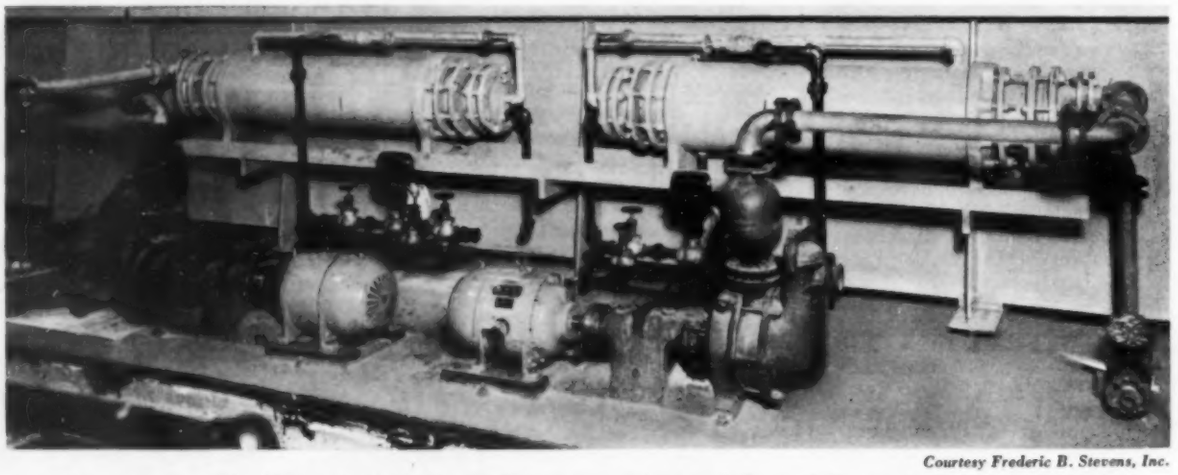
Coils



Coils are made of Duriron pipe and fittings. Standard sections are joined by welding to form the desired style. The welds are acid-resisting.



Immersion tubes are used to heat small, deep tanks or comparatively wide, shallow tanks. Made in the straight "bayonet" type and the "ell" type, as shown.



Courtesy Frederic B. Stevens, Inc.

This picture was taken during the installation of Duriron equipment—heat exchangers, pumps, valves, pipe and fittings—for the handling of cleaning solution used prior to plating. Similar equipment, not shown, was also used for the plating solution.

THE DURIRON COMPANY, Inc.
North Findlay Street — Dayton, Ohio

INDUSTRIAL CHEMICALS

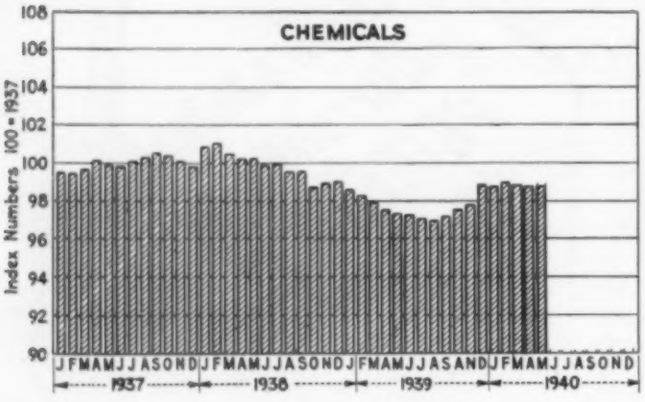
	Current Price	Last Month	Last Year
Acetone, drums, lb	$0.07½–$0.08	$0.07½–$0.08	$0.05¼–$0.06¼
Acid, acetic, 28%, bbl., cwt	2.23 – 2.48	2.23 – 2.48	2.23 – 2.48
Glacial 99%, drums	8.43 – 8.68	8.43 – 8.68	8.43 – 8.68
U. S. P. reagent	10.25 –10.50	10.25 –10.50	10.25 –10.50
Boric, bbl., ton	106.00–111.00	106.00–111.00	106.00–111.00
Citric, kegs, lb	.20 – .23	.20 – .23	.20½– .23
Formic, bbl., lb	.10½– .11	.10½– .11	.10½– .11
Gallic, tech., bbl., lb	.90 – 1.00	.90 – 1.00	.70 – .75
Hydrofluoric 30% carb., lb	.08 – .08½	.07 – .07½	.07 – .07½
Lactic, 44%, tech., light, bbl., lb	.06½– .06¾	.06½– .06¾	.06½– .06¾
Muriatic, 18°, tanks, cwt	1.05 –	1.05 –	1.05 –
Nitric, 36°, carboys, lb	.05 – .05½	.05 – .05½	.05 – .05½
Oleum, tanks, wks., ton	18.50 –20.00	18.50 –	18.50 –20.00
Oxalic, crystals, bbl., lb	.10½– .12	.10½– .12	.10½– .12
Phosphoric, tech., c'bys., lb	.07½– .08½	.07½– .08½	.07½– .08½
Sulphuric, 60°, tanks, ton	13.00 –	13.00 –	13.00 –
Sulphuric, 66°, tanks, ton	16.50 –	16.50 –	16.50 –
Tannic, tech., bbl., lb	.54 – .56	.54 – .56	.40 – .45
Tartaric, powd., bbl., lb	.37½–	.37½–	.27½–
Tungstic, bbl., lb	nom.	nom.	2.75 –
Alcohol, amyl	–	–	–
From Pentane, tanks, lb	.101–	.101–	.101–
Alcohol, Butyl, tanks, lb	.09 –	.09 –	.07½–
Alcohol, Ethyl, 190 p'f., bbl., gal	4.54 –	4.54 –	4.54 –
Denatured, 190 proof	–	–	–
No. 1 special, bbl., gal. wks.	.29½–	.29½–	.28 –
Alum, ammonia, lump, bbl., lb	.03½– .04	.03½– .04	.03½– .04
Potash, lump, bbl., lb	.03½– .04	.03½– .04	.03½– .04
Aluminum sulphate, com. bags, cwt	1.15 – 1.40	1.15 – 1.40	1.15 – 1.40
Iron free, l.g., cwt	1.60 – 1.70	1.30 – 1.55	1.30 – 1.55
Aqua ammonia, 26°, drums, lb	.02½– .03	.02½– .03	.02 – .03
tanks, lb	.02 – .02½	.02 – .02½	.02 – .02½
Ammonia, anhydrous, cyl., lb	.16 –	.16 –	.15½– .16
tanks, lb	.04½–	.04½–	.04½– .16
Ammonium carbonate, powd. tech., casks, lb	.09 – .12	.09 – .12	.08 – .12
Sulphate, wks., cwt	1.40 –	1.40 –	1.40 –
Amylacetate tech., tanks, lb	.11½–	.11½–	.10 –
Antimony Oxide, bbl., lb	.15 –	.15 –	.11 – .12
Arsenic, white, powd., bbl., lb	.03 – .03½	.03 – .03½	.03 – .03½
Red, powd., kegs, lb	.17 – .18	.15½– .16	.15½– .16
Barium carbonate, bbl., ton	52.50 –57.50	52.50 –57.50	52.50 –57.50
Chloride, bbl., ton	79.00 –81.00	79.00 –81.00	79.00 –81.00
Nitrate, casks, lb	.09 – .10	.07 – .08	.07 – .08
Blanc fixe, dry, bbl., lb	.03½– .04	.03½– .04	.03½– .04
Bleaching powder, f. o. b., wks., drums, cwt	2.00 – 2.10	2.00 – 2.10	2.00 – 2.10
Borax, gran., bags, ton	43.00 –	43.00 –	48.00 –51.00
Bromine, cs., lb	.30 – .32	.30 – .32	.30 – .32
Calcium acetate, bags	1.90 –	1.90 –	1.65 – 1.75
Arsenate, dr., lb	.06½– .06¾	.06 – .06¾	.06½– .07
Carbide drums, lb	.04½– .05	.04½– .05	.05 – .06
Chloride, fused, dr., del., ton	21.50 –24.50	21.50 –24.50	21.50 –24.50
flake, dr., del., ton	23.00 –25.00	23.00 –25.00	23.00 –25.00
Phosphate, bbl., lb	.07½– .08	.07½– .08	.07½– .08
Carbon bisulphide, drums, lb	.05 – .06	.05 – .06	.05 – .06
Tetrachloride drums, lb	.04½– .05½	.04½– .05½	.04½– .05½
Chlorine, liquid, tanks, wks., lb	1.75 –	1.75 –	1.75 –
Cylinders	.05½– .06	.05½– .06	.05½– .06
Cobalt oxide, cans, lb	1.84 – 1.87	1.84 – 1.87	1.67 – 1.70
Copperas, bgs., f. o. b., wks., ton	18.00 –19.00	17.00 –18.00	15.00 –16.00
Copper carbonate, bbl., lb	.10 – .16¼	.10 – .16¼	.10 – .16
Sulphate, bbl., cwt	4.60 – 4.85	4.60 – 4.85	4.35 – 4.60
Cream of tartar, bbl., lb	.30½–	.30½–	.22½–
Diethylene glycol, dr., lb	.22 – .23	.22 – .23	.22 – .23
Epsom salt, dom., tech., bbl., cwt	1.80 – 2.00	1.80 – 2.00	1.80 – 2.00
Ethyl acetate, drums, lb	.07 –	.07 –	.061–
Formaldehyde, 40%, bbl., lb	.05½– .06	.05¼– .06¼	.05½– .06¼
Furfural, tanks, lb	.09 –	.09 –	.09 –
Fusel oil, ref. drums, lb	.16 – .17	.16 – .17	.12½– .14
Glaubers salt, bags, cwt	.95 – 1.00	.95 – 1.00	.95 – 1.00
Glycerine, c.p., drums, extra, lb	.12½–	.12½–	.12½–
Lead:			
White, basic carbonate, dry casks, lb	.07 –	.07 –	.07 –
White, basic sulphate, sck., lb	.06½–	.06½–	.06½–
Red, dry, sck., lb	.07½–	.07½–	.07½–
Lead acetate, white crys., bbl., lb	.11 – .12	.11 – .12	.10 – .11
Lead arsenate, powd., bag, lb	.08½– .11	.08½– .11	.10 – .10½
Lime, chem., bulk, ton	8.50 –	8.50 –	8.50 –
Litharge, pwd., csk., lb	.06½–	.06½–	.06½–
Lithophone, bags, lb	.036– .04	.036– .04	.04½– .05
Magnesium carb., tech., bags, lb	.06½– .06¾	.06½– .06¾	.06 – .06½
Methanol, 95%, tanks, gal	.29 –	.31 –	.31 –
97%, tanks, gal	.30 –	.32 –	.32 –
Synthetic, tanks, gal	.30 –	.30 –	.33 –
Nickel salt, double, bbl., lb	.13 – .13½	.13 – .13½	.13 – .13½
Orange mineral, csk., lb	.10¼–	.10¼–	.10¼–
Phosphorus, red, cases, lb	.40 – .42	.40 – .42	.40 – .42
Yellow, cases, lb	.18 – .25	.18 – .25	.18 – .25
Potassium bichromate, casks, lb	.08½– .09	.08½– .09	.08½– .09
Carbonate, 80–85%, calc. csk., lb	.06½– .07	.06½– .07	.06½– .07
Chlorate, powd., lb	.10 – .12	.10 – .12	.09½–
Hydroxide(c'stic potash) dr., lb	.07 – .07¼	.07 – .07¼	.07 – .07½
Muriate, 80% bgs., unit	.53½–	.53½–	.53½–
Nitrate, bbl., lb	.05½– .06	.05½– .06	.05½– .06
Permanganate, drums, lb	.18½– .19	.18½– .19	.18½– .19
Prussiate, yellow, casks, lb	.15 – .16	.15 – .16	.14 – .15
Sal ammoniac, white, casks, lb	.05 – .06	.05½– .06	.05 – .05½
Salsoda, bbl., cwt	1.00 – 1.05	1.00 – 1.05	1.00 – 1.05
Salt cake, bulk, ton	23.00 –	23.00 –	13.00 –15.00
Soda ash, light, 58%, bags, contract, cwt	1.05 –	1.05 –	1.05 –
Dense, bags, cwt	1.10 –	1.10 –	1.10 –
Soda, caustic, 76%, solid, drums, cwt	2.30 – 3.00	2.30 – 3.00	2.30 – 3.00
Acetate, works, bbl., lb	.04 – .05	.04 – .05	.04 – .05
Bicarbonate, bbl., cwt	1.70 – 2.00	1.70 – 2.00	1.70 – 2.00
Bichromate, casks, lb	.06½– .07	.06½– .07	.06½– .07
Bisulphate, bulk, ton	15.00 –16.00	15.00 –16.00	15.00 –16.00
Bisulphite, bbl., lb	.03 – .04	.03½– .04	.03½– .04
Chlorate, kegs, lb	.06½– .06½	.06½– .06½	.06½– .06¾
Cyanide, cases, dom., lb	.14 – .15	.14 – .15	.14 – .15
Fluoride, bbl., lb	.07 – .08	.07½– .08	.07½– .08
Hyposulphite, bbl., cwt	2.40 – 2.50	2.40 – 2.50	2.40 – 2.50
Metasilicate, bbl., cwt	2.35 – 2.40	2.35 – 2.40	2.20 – 3.20
Nitrate, bulk, cwt	1.45 –	1.45 –	1.45 –
Nitrite, casks, lb	.06½– .07	.06½– .07	.06½– .07
Phosphate, tribasic, bags, lb	2.25 –	2.25 –	2.10 –
Prussiate, yel. drums, lb	.10½– .11	.10½– .11	.09½– .10
Silicate (40° dr.) wks., cwt	.80 – .85	.80 – .85	.80 – .85
Sulphide, fused, 60–62%, dr., lb	.02½– .03½	.02½– .03	.02½– .03
Sulphite, crys., bbl., lb	.02½– .02½	.02½– .02¾	.02½– .02¾
Sulphur, crude at mine, bulk, ton	16.00 –	16.00 –	18.00 –
Chloride, dr., lb	.03 – .04	.03 – .04	.03 – .04
Dioxide, cyl., lb	.07 – .08	.07 – .08	.07 – .07½
Flour, bag, cwt	1.60 – 3.00	1.60 – 3.00	1.60 – 3.00
Tin Oxide, bbl., lb	.51 –	.52 –	.50 –
Crystals, bbl., lb	.36 –	.36½–	.38 –
Zinc, chloride, gran., bbl., lb	.05 – .06	.05 – .06	.05 – .06
Carbonate, bbl., lb	.14 – .15	.14 – .15	.14 – .15
Cyanide, dr., lb	.33 – .35	.33 – .35	.33 – .35
Dust, bbl., lb	.07½–	.07½–	.06½–
Zinc oxide, lead free, bag., lb	.06½–	.06½–	.06½–
5% lead sulphate, bags, lb	.06½–	.06½–	.06½–
Sulphate, bbl., cwt	2.75 – 3.00	2.75 – 3.00	2.75 – 3.00

OILS AND FATS

	Current Price	Last Month	Last Year
Castor oil, 3 bbl., lb	$0.11½–$0.12	$0.11½–$0.12	$0.08½–$0.10
Chinawood oil, bbl., lb	.24 –	.24½–	.17½–
Coconut oil, Ceylon, tank, N. Y., lb	.03½–	.03½–	.03½–
Corn oil crude, tanks (f. o. b. mill), lb	.06½–	.06½–	.06–
Cottonseed oil, crude (f. o. b. mill), tanks, lb	.05½–	.05½–	.05½–
Linseed oil, raw car lots, bbl., lb	.106–	.108–	.088–
Palm, casks, lb	.04½–	.04½–	.03½–
Peanut oil, crude, tanks (mill), lb	.06¼–	.06¼–	.05½–
Rapeseed oil, refined, bbl., gal	1.05 –	1.00 –	.80 –
Soya bean, tank, lb	.05½–	.05½–	.05 –
Sulphur (olive foots), bbl., lb	.08½–	.08½–	.06½–
Cod, Newfoundland, bbl., gal	nom.	nom.	.38 –
Menhaden, light pressed, bbl., lb	.073–	.073–	.066–
Crude, tanks (f. o. b. factory), gal	.33 –	.33 –	.30 –
Grease, yellow, loose, lb	.04½–	.04½–	.05 –
Oleo stearine, lb	.06½–	.05½–	.06½–
Oleo oil, No. 1	.06½–	.06¼–	.07½–
Red oil, distilled, d.p. bbl., lb	.08 –	.08 –	.07½–
Tallow extra, loose, lb	.04½–	.04¼–	.05¼–

The accompanying prices refer to round lots in the New York market. Where it is the trade custom to sell f.o.b. works, quotations are given on that basis and are so designated. Prices are corrected to May 14

Chem. & Met.'s Weighted Price Indexes


CHEMICALS
Index Numbers, 100 = 1937
108
106
104
102
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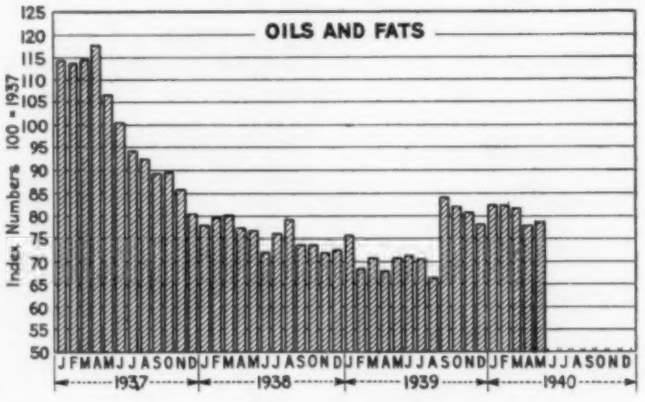
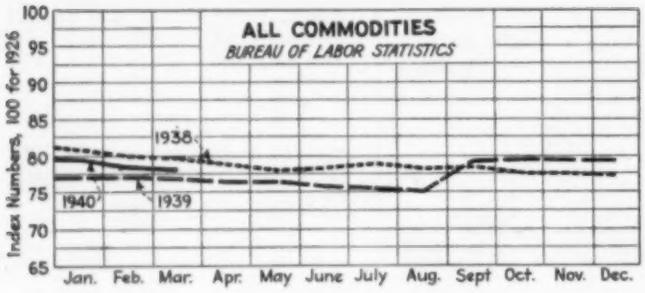
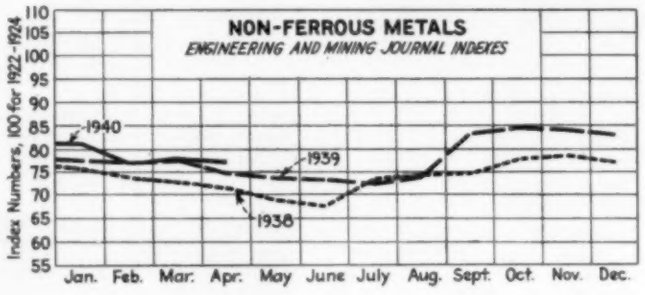






Coal-Tar Products

	Current Price	Last Month	Last Year
Alpha-napthol, crude bbl., lb	$0.52 –$0.55	$0.52 –$0.55	$0.52 –$0.55
Alpha-naphthylamine, bbl., lb	.32 – .34	.32 – .34	.32 – .34
Aniline oil, drums, extra, lb	.15 – .16	.15 – .16	.15 – .16
Aniline, salts, bbl., lb	.22 – .24	.22 – .24	.22 – .24
Benzaldehyde, U.S.P., dr., lb	.85 – .95	.85 – .95	.85 – .95
Benzidine base, bbl., lb	.70 – .75	.70 – .75	.70 – .75
Benzoic acid, U.S.P., kgs., lb	.54 – .56	.54 – .56	.54 – .56
Benzyl chloride, tech., dr., lb	.23 – .25	.23 – .25	.23 – .25
Benzol, 90%, tanks, works, gal	.16 –.....	.16 – .18	.16 – .18
Beta-napthol, tech., drums, lb	.23 – .24	.23 – .24	.23 – .24
Cresol, U.S.P., dr., lb	.09½– .10	.09½– .10	.10 – .11
Cresylic acid, dr., wks., gal	.58 – .60	.58 – .60	.69 – .71
Diethylaniline, dr., lb	.40 – .45	.40 – .45	.40 – .45
Dinitrophenol, bbl., lb	.23 – .25	.23 – .25	.23 – .25
Dinitrotoluen, bbl., lb	.15½– .16	.15½– .16	.15 – .16
Dip oil, 15%, dr., gal	.23 – .25	.23 – .25	.23 – .25
Diphenylamine, bbl., lb	.25 – .27	.32 – .36	.32 – .36
H-acid, bbl., lb	.50 – .55	.50 – .55	.50 – .55
Naphthalene, flake, bbl., lb	.06½– .07	.06½– .07	.05½– .06
Nitrobenzene, dr., lb	.08 – .09	.08 – .09	.08 – .09
Para-nitraniline, bbl., lb	.47 – .49	.47 – .49	.47 – .49
Phenol, U.S.P., drums lb	.13 –.....	.13 –.....	.14½–.....
Picric acid, bbl., lb	.35 – .40	.35 – .40	.35 – .40
Pyridine, dr., gal	1.70 – 1.80	1.70 – 1.80	1.55 – 1.60
Resorcinal, tech., kegs, lb	.75 – .80	.75 – .80	.75 – .80
Salicylic acid, tech., bbl., lb	.33 – .40	.33 – .40	.33 – .40
Solvent naptha, w.w., tanks, gal	.27 –.....	.27 –.....	.26 –.....
Tolidine, bbl., lb	.86 – .88	.86 – .88	.86 – .88
Toluene, drums, works, gal	.30 –.....	.30 –.....	.27 –.....
Xylene, com, tanks, gal	.27 –.....	.27 –.....	.26 –.....

Miscellaneous

	Current Price	Last Month	Last Year
Barytes, grd., white, bbl., ton	$22.00–$25.00	$22.00–$25.00	$22.00–$25.00
Casein, tech., bbl., lb	.11 – .13	.10 – .14	.07½– .11
China clay, dom., f.o.b. mine, ton	8.00 –20.00	8.00 –20.00	8.00 –20.00
Dry colors			
Carbon gas, black (wks.), lb	.028– .30	.02½– .30	02½– .30
Prussian blue, bbl., lb	.36 – .37	.36 – .37	.36 – .37
Ultramarine blue, bbl., lb	.11 – .26	.11 – .26	.10 – .26
Chrome green, bbl., lb	.21½– .30	.21½– .30	.21 – .27
Carmine red, tins, lb	4.85 – 5.00	4.85 – 5.00	4.00 – 4.40
Para toner, lb	.75 – .80	.75 – .80	.75 – .80
Vermilion, English, bbl., lb	2.46 – 2.50	2.85 – 2.90	1.58 – 1.60
Chrome yellow, C.P., bbl., lb	.14½– .15½	.14½– .15½	.14½– .15½
Feldspar, No. 1 (f.o.b. N.C.), ton	6.50 – 7.50	6.50 – 7.50	6.50 – 7.50
Graphite, Ceylon, lump, bbl., lb	.06 – .06¼	.06 – .06½	.06 – .06¼
Gum copal Congo, bags, lb	.08 – .30	.08 – .30	.06 – .30
Manila, bags, lb	.09 – .15	.09 – .14	.09 – .14
Damar, Batavia, cases, lb	.10 – .22	.10 – .20	.08 – .24
Kauri, cases, lb	.18 – .60	.18 – .60	.18½– .60
Kieselguhr (f.o.b. N.Y.), ton	50.00 –55.00	50.00 –55.00	50.00 –55.00
Magnesite, calc, ton	50.00 –.....	50.00 –.....	50.00 –.....
Pumice stone, lump, bbl., lb	.05 – .07	.05 – .08	.05 – .07
Imported, casks, lb	.03 – .04	.03 – .04	.03 – .04
Rosin, H., bbl	6.25 –.....	6.95 –.....	6.20 –.....
Turpentine, gal	.34 –.....	.36½–.....	.30½–.....
Shellac, orange, fine, bags, lb	.27 –.....	.28 –.....	.19 –.....
Bleached, bonedry, bags, lb	.25 –.....	.25 –.....	.18 –.....
T. N. Bags, lb	.14½–.....	.16½–.....	.10 –.....
Soapstone (f.o.b. Vt.), bags, ton	10.00 –12.00	10.00 –12.00	10.00 –12.00
Talc, 200 mesh (f.o.b. Vt.), ton	8.00 – 8.50	8.00 – 8.50	8.00 – 8.50
300 mesh (f.o.b. Ga.), ton	7.50 –10.00	7.50 –10.00	7.50 –11.00
225 mesh (f.o.b. N.Y.), ton	13.75 –.....	13.75 –.....	13.75 –.....

Industrial Notes

WISHNICK-TUMPEER, INC., New York, has appointed C. A. Hemingway manager of its office in Cleveland.

THE CLEVELAND CRANE & ENGINEERING CO., Wickliffe, Ohio, announces that the Cleveland Tamrail Erie Co., its distributor in the Erie, Pa., territory, has moved to 1731 Oxford St., Erie. H. M. Nelson is manager of the office.

ROBINS CONVEYING BELT CO., New York, has moved its offices to Passaic, N. J., where a three-story office building has been erected near the company's plant. A sales office will be maintained in New York at 70 Pine St.

RID-O-MOTH CORP., Kearny, N. J., has been organized for the manufacture of paradichlorobenzine. A. Weiner of the Standard Naphthalene Products Co. is president of the new corporation.

KRUMBHAAR CHEMICALS, INC., South Kearny, N. Y., has appointed D. H. Litter Co., Inc., as sales agents for its modified phenolic resins.

GENERAL ELECTRIC CO., Schenectady, N. Y., has transfered Chester H. Lang from manager of advertising and sales promotion activities to manager of apparatus sales.

F. J. STOKES MACHINE CO., Philadelphia, reports that its molding equipment representative in the metropolitan district, A. C. Wiebe, has moved to 103 Park Ave., New York.

INTERCHEMICAL CORP., New York, has formed an export division to unify its foreign sales efforts. C. A. Richards is in charge of the new division.

PHILADELPHIA COKE CO., Philadelphia, has awarded contract for a new plant which will produce light oils and motor fuel.

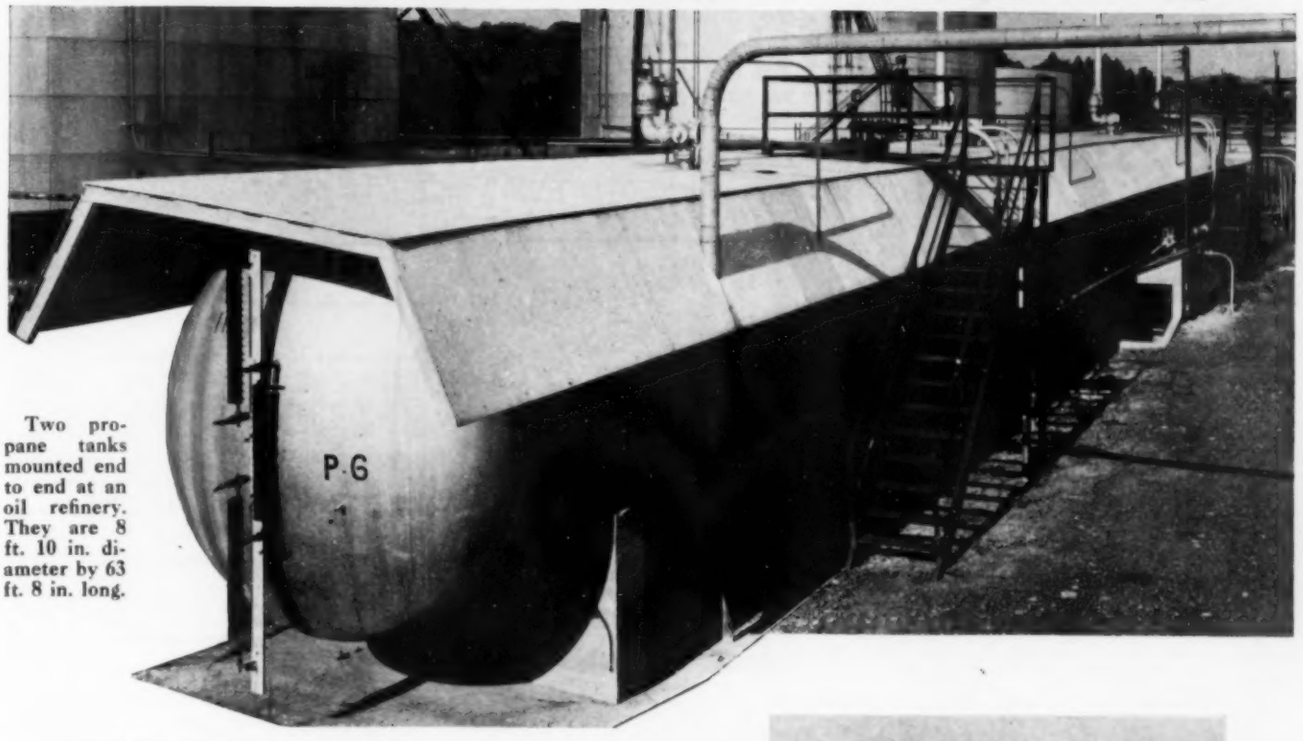
EAGLE-PICHER SALES CO., Cincinnati, has appointed Otto Hense sales manager of its pigment division.

STROOCK & WITTENBERG CORP., New York, has appointed the C. W. Hess Co., Detroit, as sales representative in Michigan.

PITTSBURGH IRON & COKE CO., Pittsburgh, has appointed R. W. Greeff & Co., New York, as its representative for the sale of sal ammoniac and anhydrous sodium sulphate.

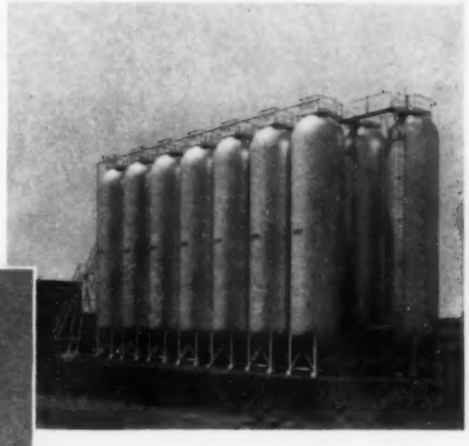
THE INTERNATIONAL NICKEL CO., New York, will add an additional electric heat treating furnace and other equipment to its plant at Huntington, W. Va., and will erect a new unit for its chemical and physical laboratories.

Welded PRESSURE VESSELS

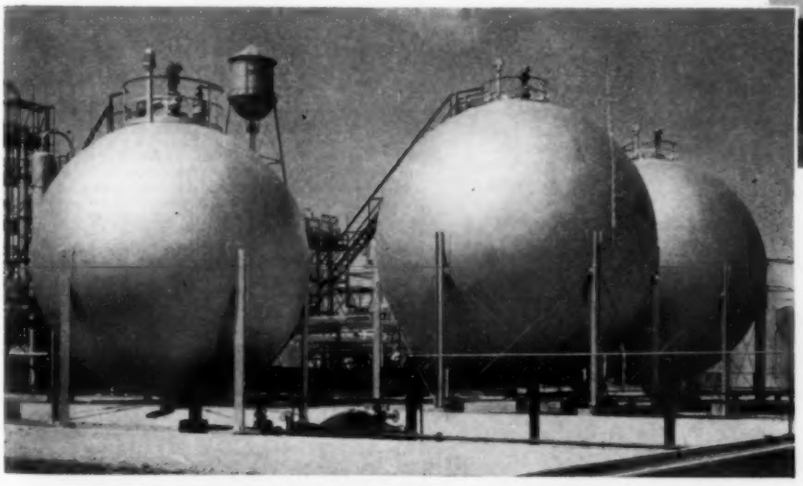


Two propane tanks mounted end to end at an oil refinery. They are 8 ft. 10 in. diameter by 63 ft. 8 in. long.

We are equipped to build pressure vessels in any size or shape to meet your requirements. Hortonspheres come in standard capacities up to 15,000 bbls. Vertical tanks are built up in the shop and shipped complete in capacities up to 1,000 bbls. ready to set up and use. Cylindrical vessels supplied to API-ASME specifications; those requiring x-raying and stress-relieving shipped from Birmingham. Write for quotations.



A battery of vertical pressure tanks holding 1,000 bbls. each designed for 50 lbs. per sq. in. pressure.



A 1,000-bbl. Hortonsphere for 250 lbs. and two 4,000 bbl. units for 100 lbs. per sq. in. pressure used to store volatile liquids.

Horton pressure vessels—whether spherical, spheroidal of cylindrical in shape—provide economical means for handling and storage of gases of all types. There are no water seals to cause contamination or to require heating and maintenance.

CHICAGO BRIDGE & IRON COMPANY

Chicago	2124 McCormick Bldg.	Philadelphia	1625-1700 Walnut Street Bldg.	Houston	2919 Main Street
Detroit	1503 Lafayette Bldg.	Cleveland	2220 Rockefeller Bldg.	Tulsa	1623 Hunt Bldg.
New York	3318-165 Broadway Bldg.	Birmingham	1510 North Fiftieth Street	Los Angeles	1405 Wm. Fox Bldg.
Boston	1503 Consolidated Gas Bldg.	Dallas	1405 Liberty Bank Bldg.	San Francisco	1022 Rialto Bldg.

PLANTS IN BIRMINGHAM, CHICAGO AND GREENVILLE, PA. *In Canada:* HORTON STEEL WORKS, LIMITED, FORT ERIE, ONT.

Chem & Met New CONSTRUCTION

	Current Projects		Cumulative 1940	
	Proposed Work	Contracts	Proposed Work	Contracts
New England	$200,000	$120,000	$240,000	$368,000
Middle Atlantic	40,000	1,880,000	7,765,000	3,317,000
South	840,000	.....	11,835,000	14,565,000
Middle West	40,000	190,000	6,725,000	2,490,000
West of Mississippi	6,120,000	1,990,000	15,375,000	11,261,000
Far West	3,045,000	50,000	4,950,000	3,878,000
Canada	3,310,000	190,000	6,055,000	390,000
Total	$13,595,000	$4,420,000	$52,945,000	$36,269,000

PROPOSED WORK

Alumina Reduction Plant—Aluminum Co. of America, Gulf Bldg., Pittsburgh, Pa., plans to construct a second reduction plant at Vancouver, Wash. Estimated cost $3,000,000.

Cellulose Plant—Burgess Cellulose Co., Ltd., c/o R. W. Hart, 350 Bay St., Toronto, Ont., Can., plans to construct a plant for the manufacture of cellulose and its products. Estimated cost $40,000.

Chemical Plant—Morningside Chemical Co., 202 Morningside Dr., Chattanooga, Tenn., is having plans prepared by Critchfield & Law, Archts. & Engrs., 809 Pine St., Chattanooga, for a 1 story plant. Estimated cost $150,000.

Fertilizer Plant—Colonial Fertilizer Co., Ltd., c/o Arthur G. Hastings, 178 Atlantic Ave., Boston, Mass., plans to construct a fertilizer plant at Windsor, Ont., Can. Estimated cost $50,000.

Gypsum Plant— U. S. Gypsum Co., 300 West Adams St., Chicago, Ill., plans to construct a 1 story, 50x200 ft. addition to its plant. Estimated cost $40,000.

Oil Refinery—British American Oil Co., Ltd., Canada Cement Bldg., Montreal, Que., Can., plans to build an addition to its oil refinery in Laval Co., Montreal E. Estimated cost $40,000.

Oil Refinery—Petroleum Producers, Ltd., Calgary, Alta., Can., plans to construct an oil refinery. Estimated cost $50,000.

Oil Refinery—Texas Refining Co., c/o K. Kimbell, 2330 Medford Court E., Fort Worth, Tex., has purchased the plant of J. D. Middleton at Greenville, Tex., and plans to improve and enlarge same. Estimated cost will exceed $40,000.

Oil Tempering Plant—Midvale Co., Wissahockon Ave., Philadelphia, Pa., plans to construct an oil tempering plant. Contract for foundations has been awarded to Carter Paving Co., 50th and Lancaster Ave., Philadelphia. Estimated cost will exceed $40,000.

Paper Mill—H. Smith Paper Mills, Ltd., 407 McGill St., Montreal, Que., Can., plans to construct an addition to its mill at Joliette, Que. Estimated cost $40,000.

Paper Mill—Southland Mills, Inc., c/o E. L. Kurth, Pres., Lufkin, Tex., plans to construct and equip a new unit at its plant. Estimated cost $6,000,000.

Pottery Plant—Central Pottery, Ltd., St. Johns, Que., Can., plans to construct a plant at Iberville, Que. Estimated cost $40,000.

Powder Plant—U. S. Navy Dept., Washington, D. C., plans to construct a powder manufacturing unit at the Naval Torpedo Station, Newport, R. I. Estimated cost $200,000.

Pulp Plant—Bloedel-Stewart-Welch, Ltd., Port Alberni, B. C., Can., contemplates the construction of a pulp and paper mill. Estimated cost $3,000,000.

Pyrotechnic Plant—International Flare Signal Co., Ltd., Waterloo, Que., Can., plans to construct a pyrotechnic manufacturing plant. Estimated cost $50,000.

Rayon Mill—American Bemberg Co., Elizabethton, Tenn., plans to enlarge and build an addition to its plant. Estimated cost $650,000.

Soy Bean Plant—Owner c/o Chamber of Commerce, J. Carroll, Pres., Spencer, Ia., plans to construct a soy bean processing plant. Estimated cost will exceed $40,000.

Sulphur Plant—Valley Sulphur Co., Lodi, Calif., plans to rebuild its plant recently destroyed by fire. Estimated cost $45,000.

Starch Plant—Athens Cooperative Starch Plant, c/o I. Jalonick, Athens, Tex., plans to construct and equip a sweet potato starch plant, potato dehydration plant and by-products. Estimated cost will exceed $40,000.

Tire Factory—Dixie Tire Co., 101 S. W. First St., Miami, Fla., plans to construct an addition to its plant.

CONTRACTS AWARDED

Alpaste Plant—Aluminum Co. of Canada, Ltd., Dominion Sq. Bldg., Montreal, Que., Can., has awarded the contract for the construction of a plant for the manufacture of Alpaste, a pigment used by paint manufacturers, at Arvida, Que., to Foundation Co. of Canada, Ltd., 1538 Sherbrooke St., W., Montreal, Que. Estimated cost $100,000.

Asphalt Plant—Idaho Refining Co., Pocatello, Idaho, will construct an asphalt plant by force account. Estimated cost $50,000.

Calcium Arsenate Plant—Cotton Poisons, Inc., O. C. Behse, Mgr., Bryan, Tex., plans to construct and equip a cotton poison manufacturing plant. First product to be manufactured will be calcium arsenate. Work will be done by day labor. Estimated cost $40,000.

Chemical Plant—Althouse Chemical Co., 500 Pear St., Reading Pa., has awarded the contract for a 3 story addition to its plant to L. H. Focht & Son, Inc., Reading. Estimated cost including equipment $40,000.

Chemical Plant—Harshaw Chemical Co., 1945 East 97th St., Cleveland, O., has awarded the contract for an addition to its plant to James C. F. Shafer Co., Caxton Bldg., Cleveland. Estimated cost $40,000.

Creosote Treating Plant—Garrison Creosote Treating Plant, c/o C. S. Jones, Pres., Nacogdoches, Tex., will construct and equip a creosote treating plant at Garrison, Tex. Work will be done by force account. Estimated cost $60,000.

Factory—Canadian Industries, Ltd., Burlington St., Hamilton, Ont., Can., manufacturer of chemicals and fertilizers, will alter its plant. Work will be done with own forces. Estimated cost $50,000.

Factory—Eastern Tablet Corp., (subsidiary of United Drug Co.) 1315 Bway., Albany, N. Y., has awarded the contract for a 2 story addition to its plant to Thomas Mulcare Corp., 414 Mt. Auburn St., Cambridge, Mass. Estimated cost will exceed $40,000.

Glass Factory—Armstrong Cork Co., South Second St., Millville, N. J., has awarded the contract for the construction of a glass manufacturing factory to Irwin & Leighton, Schaff Bldg., Philadelphia, Pa. Estimated cost $100,000.

Graphite Plant—Acheson Graphite Corp., Buffalo Ave., Niagara Falls, N. Y., has awarded the contract for an addition to its plant to Walter S. Johnson Building Co., 2532 Hyde Park Blvd., Niagara Falls. Estimated cost $40,000.

Pharmaceutical Manufacturing Plant—Andrew Jergens Co., 2535 Spring Grove Ave., Cincinnati, O., has awarded the contract for a plant at Belleville, N. J., to James Stewart & Co., 230 Park Ave., New York, N. Y. Estimated cost $1,000,000.

Plastics Factory—Fuller Brush Co., 3580 Main St., Hartford, Conn., has awarded the contract for a 1 story, 128x180 ft. factory to Robert G. Bent Co., 93 Edwards St., Hartford. Estimated cost $70,000.

Plastics Factory—General Electric Co., 570 Lexington Ave., New York., N. Y., has awarded the contract for a plastics manufacturing factory at Pittsfield, Mass., to J. W. Bishop Co., 109 Foster St., Worcester, Mass. Work is under way. Estimated cost $50,000.

Pottery Plant—Canada Potteries, Ltd., 5 Mackenzie King St., St. Johns, Que., Can., has awarded the contract for the construction of a plant to Leopold Roy & Sons, Ltd., 197 St. James St., St. Johns. Estimated cost $40,000.

Recycling Plant—American Oil Co., Grapeland and Crockett, Tex., has awarded the contract for a new unit at its plant to Fowser Construction Co., Inc., M. & M. Bldg., Houston, Tex. Estimated cost $90,000.

Recycling Plant—Coronado Corp., Continental Bldg., Dallas, Tex., has awarded the contract for constructing and equipping a recycling plant in the LaRosa Field of Refugio Co., to Gasoline Plant Construction Co., Second Natl. Bank Bldg., Houston, at $360,000. Total estimated cost including machinery and equipment $550,000.

Roofing Factory—American Asphalt Roofing Corp., 15th and Blue River Sts., Kansas City, Mo., has awarded the contract for a factory at Fort Worth, Tex., to T. S. Byrne, Fort Worth Natl. Bank Bldg., Fort Worth. Estimated cost $250,000.

Roofing Factory—Certain-Teed Products Corp., 100 East 42nd St., New York, N. Y., will modernize and improve its roofing products factory at York, Pa. Work will be done by separate contracts. Estimated cost $250,000.

Rubber Factory—B. F. Goodrich Co., 1955 Hunting Park Ave., Philadelphia, Pa., has awarded the contract for addition to its plant, including warehouse and office, to Hughes-Foulkrod Co., Schaff Bldg., Philadelphia. Estimated cost $320,000.

Soap Products Plant—Procter & Gamble Co., Cincinnati, O., has awarded the contract for a plant at Dallas, Tex., to H. K. Ferguson Co., Hanna Bldg., Cleveland, O. Estimated cost $1,000,000.

Fireproofing Warehouse—General Fireproofing Co., East Dennick Ave., Youngstown, O., has awarded the contract for a warehouse addition to its Logan Ave. plant to Gilmore, Carmichae & Olsen, 1873 East 55th St., Cleveland, O. Estimated cost $150,000.

Paper Warehouse—Hammermill Paper Co., Erie, Pa., has awarded the contract for a 1 story, 120x140 ft. warehouse to Henry Shenk Co., 1115 Sassafras St., Erie. Estimated cost $40,000.

Paper Warehouse—Smith & Ault Paper Co., Penn St. and Kings Mill Rd., York, Pa., has awarded the contract for a 2 story warehouse to Dietz A. Smith, York. Estimated cost $50,000.